ELECTRONIC WARFARE SUPPORT JAMMING PRE-MISSION ROUTE OPTIMIZATION

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THESIS

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PRE-MISSION ROUTE OPTIMIZATION

by

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An algorithm is developed to determine an optimum route for an ECM support aircraft. Constraints imposed on the problem include aircraft speed limitations, tolerable exposure of the ECM aircraft to enemy fire, and available jammer assets. A priori information required to implement the program consists only of the hostile electronic order of battle and the strike group route. The program is purposely simplified to enable future transfer to smaller minicomputers available to the electronic warfare squadrons

ELECTRONIC WARFARE SUPPORT JAMMING PRE-MISSION ROUTE OPTIMIZATION

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ABSTRACT

An algorithm is developed to determine an optimum route for an ECM support aircraft. Constraints imposed on the problem include aircraft speed limitations, tolerable exposure of the ECM aircraft to enemy fire, and available jammer assets. A priori information required to implement the program consists only of the hostile electronic order of battle and the strike group route. The program is purposely simplified to enable future transfer to smaller minicomputers available to the electronic warfare squadrons.

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I. INTRODUCTION

A. THE ROUTE PLANNING PROBLEM

In the past, a great deal of effort has gone into development of new airborne electronic warfare equipment. Extensive tests and evaluation of these systems have been conducted to optimize their performance against threat systems. When delivered to the fleet, they truly represent good systems, but it seems that the optimization stops at that time. The systems, with computer assistance, perform well for the situations and environments they are subjected to, but what is often overlooked is the fact that the operator has some control over these situations and environments.

In the airborne ECM support mission, the policy has been to fly one of two profiles; the escort or the stand off route. In the escort role, the ECM aircraft flies in the strike group formation and concentrates his assets on the terminal threat radars. This may be advantageous in some situations, but for the most part, with the threat density and Home-On-Jam (HOJ) capability of current missiles, the ECM aircraft would only serve as a billboarding threat magnet and his chances of survival would be slim. Also, after ordnance delivery, he would be unable to keep the speed of the exiting strike group, and the advantage of radar-strike aircraft-jammer alignment would be lost. In the stand off role the ECM aircraft does not penetrate any of the threat envelopes and concentrates his assets

primarily on the wider beamed search and acquisition (ACQ) radars. This is a good tactic where ECM aircraft exposure must be minimized, but good radar-strike aircraft-jammer alignment is sacrificed and excessive range of the jammer occurs.

The modified escort route has been suggested as a compromise between the escort and standoff routes. In this route, the ECM aircraft flies an escort role until a predetermined point where it alters course to avoid high exposure areas and rejoins the strike group on their exit leg. This type mission offers some of the increased performance of the escort role while retaining some of the survivalibility of the stand off role.

If presented with a strike route, the EOB, permissible ECM aircraft threat exposure, jammer assets, and speed, the operator can determine a route which maximizes the jamming effectiveness against enemy emitters for these conditions. Current planning documents and tactical manuals give the ECM operator the necessary information to determine the effectiveness against a single radar from any given point. If the operator flies anything other than a pure escort role he must determine which radars to concentrate his assets upon; i.e., he must determine a priority for each emitter. These priorities will change as the strike group progresses along its route. For each position of the strike route the operator must check all possible locations for his jammer platform to come up with the best possible position for his aircraft. He then repeats this process for each position of the strike route, each time re-prioritizing each emitter and checking each possible jammer location to determine his optimum position. When he has performed all these calculations he must select within the aircraft speed limitations, the route for maximum jamming effectiveness. For a moderately dense environment and a simple strike route

it would take an operator days to research all information and perform the calculations necessary to develop an optimum ECM route.

B. PROGRAM DESCRIPTION

The problem of determining an optimum route does not lend itself well to a continuous solution by conventional techniques. Because of the fixed number of jammers on board the aircraft and the rather abrupt lethal envelopes of the threat systems, there arise many sharp discontinuities which defy the continuous solution. In a very short period of time the various emitter priorities can change grossly and jammer assignments should instantly change. As a result of this the problem must be approached as a series of static situations which can be solved within the constraints. An optimum route can then be determined by using dynamic programming techniques [Ref. 1].

A program to accomplish this has been developed. It does not generate the absolute optimum route since this would take far more computer size and time than will be available to the aircrew. Because of the constraint of ECM aircraft maximum speed, a majority of the points calculated in the absolute optimization would have to be discarded anyway, since they could not be reached by the aircraft in the time available. Several approaches to the problem were tried. The method chosen represents a nearly optimum route and is obtained with a small program size and short execution time. Essentially, the program determines the point where the strike group exposure is greatest and for this time computes the absolute optimum position for the jammer platform within its own tolerable exposure limits. It then computes a high performance route to and from this

point. For the typical environment where the strike group exposure increases monotonically to this maximum, the route generated should approach the absolute optimum. It should be pointed out at this time that the program generates a horizontal flight route only. As such, all beam widths and radiation patterns referred to are in the horizontal plane.

The basic program flow is seen in Fig 1 . It is comprised primarily of two parallel paths. The strike route is input as a series of points that are separated by one minute in time. After the allowable jammer positions and the point of highest exposure to the strike group are computed, the ten best positions for the jammer platform are determined from all the allowable positions. Ten was selected as a reasonable number considering the characteristics of the Wang 2200 computer expected to be available to the operator. The strike route is then divided into two segments about the highest exposure point. The program then takes parallel paths for each segment. Starting with the first of the ten possible jammer positions at the high exposure point, a circle with radius equal to the one minute flight distance of the ECM aircraft is drawn. The performance for the next strike route point in the segment is then computed from every point in the circle with the highest being retained as the next ECM route point. This point becomes the center of the circle for the next time slot and the process is repeated. The routes generated for both segments are then joined together to form an ECM route. The performances at each point are summed for a measure of effectiveness (MOE) for the route. A route is generated for each of the ten highest performance jammer positions determined for the strike group's greatest exposure point, and the operator has his choice of the routes based on the MOE.

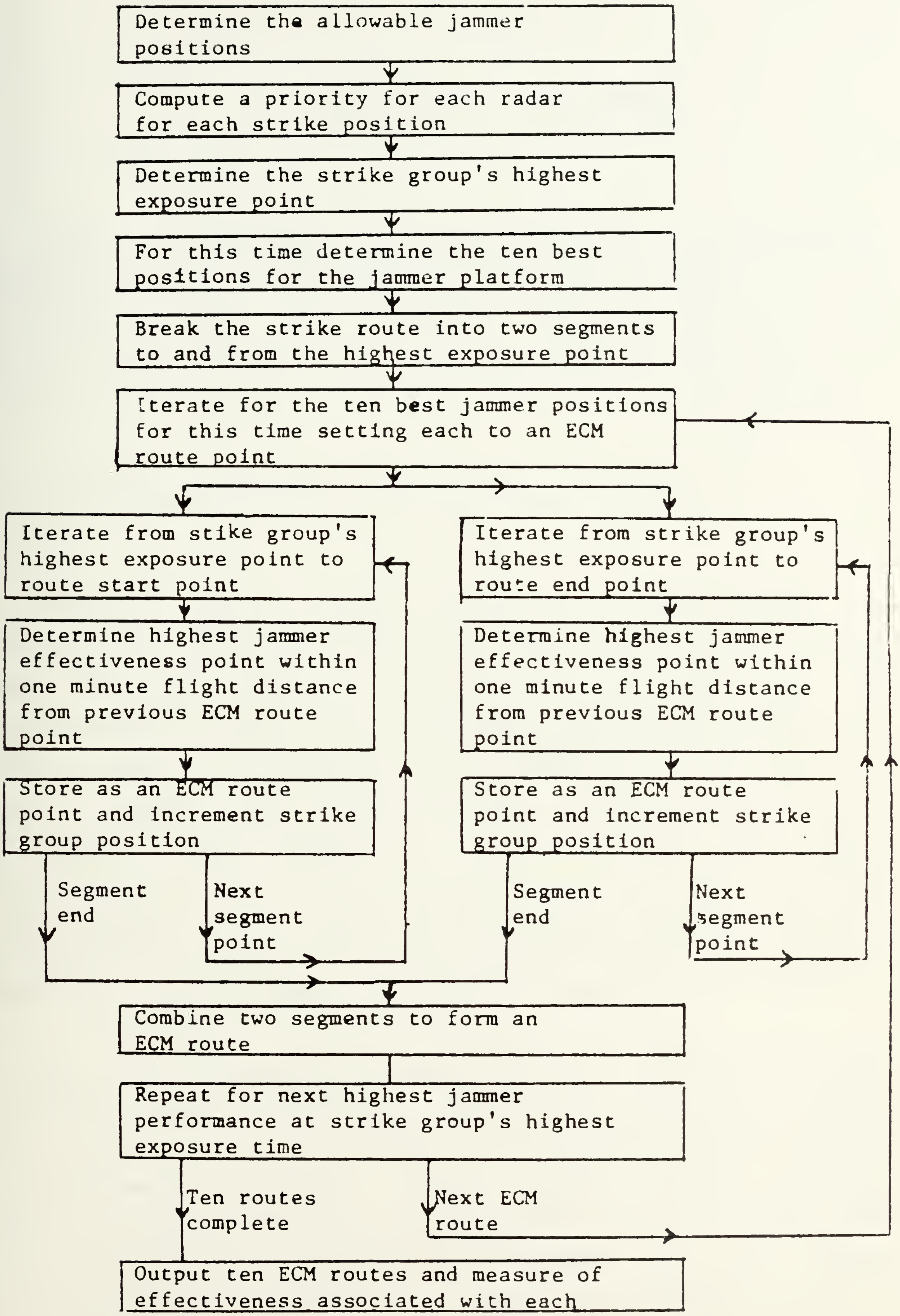

Figure 1 - BASIC PROGRAM FLOW

II. PRELIMINARY CALCULATIONS

Before the jamming effectiveness values are determined, there are some preliminary calculations which must be performed. First, the allowable positions for the ECM aircraft must be defined, and then for each position of the strike route, a priority must be assigned to each emitter.

A. ALLOWABLE POSITIONS FOR THE JAMMER PLATFORM

If there were an unlimited supply of ECM aircraft and crews, there would be no problem determining a route to fly. Every mission would be flown as an escort role and effectiveness would be outstanding until such time as the ECM aircraft was destroyed by HOJ missiles. Such is not the case, however, since these aircraft and their crews are few in number and very expensive. They also lack the flight performance characteristics essential to fly escort with the strike group in a high threat area. It is therefore necessary to restrict the operation of the ECM aircraft to areas of lower exposure to terminal threats.

For this program a pucker factor is used to determine allowable areas of operation. This pucker factor is input by the operator. It is a measure of his permissable exposure to enemy weapons systems. If the pucker factor is zero, then no threat envelopes are penetrated; if it is one, there are no restrictions, and the ECM aircraft may fly through areas where his probability of being hit approaches unity if he is selected as a weapon system target. The pucker factor

may be anywhere in the range zero to one, and the operator is free to select the value he determines to be necessary for the success of the mission.

The probability of a kill vs. range for a typical weapon system is seen in Fig 2. To obtain an approximation of this curve suitable for computer calculations, it was first necessary to generate a curve of probability of survival as a function of range. The model chosen is given by equation (1).

$$P(\text{SURVIVAL}) = \left(\frac{r}{R_L}\right)^n \tag{1}$$

Where:

r = range of aircraft at time of launch

R_L = maximum lethal range of weapon

n = emitter parameter

The parameter n is dependent upon the lethality of the weapon. A plot of this survivability vs. range is seen in Fig 3 with n = 4. The low kill probability at the short range is ignored since the aircraft would have to fly through the higher exposure area to reach that point.

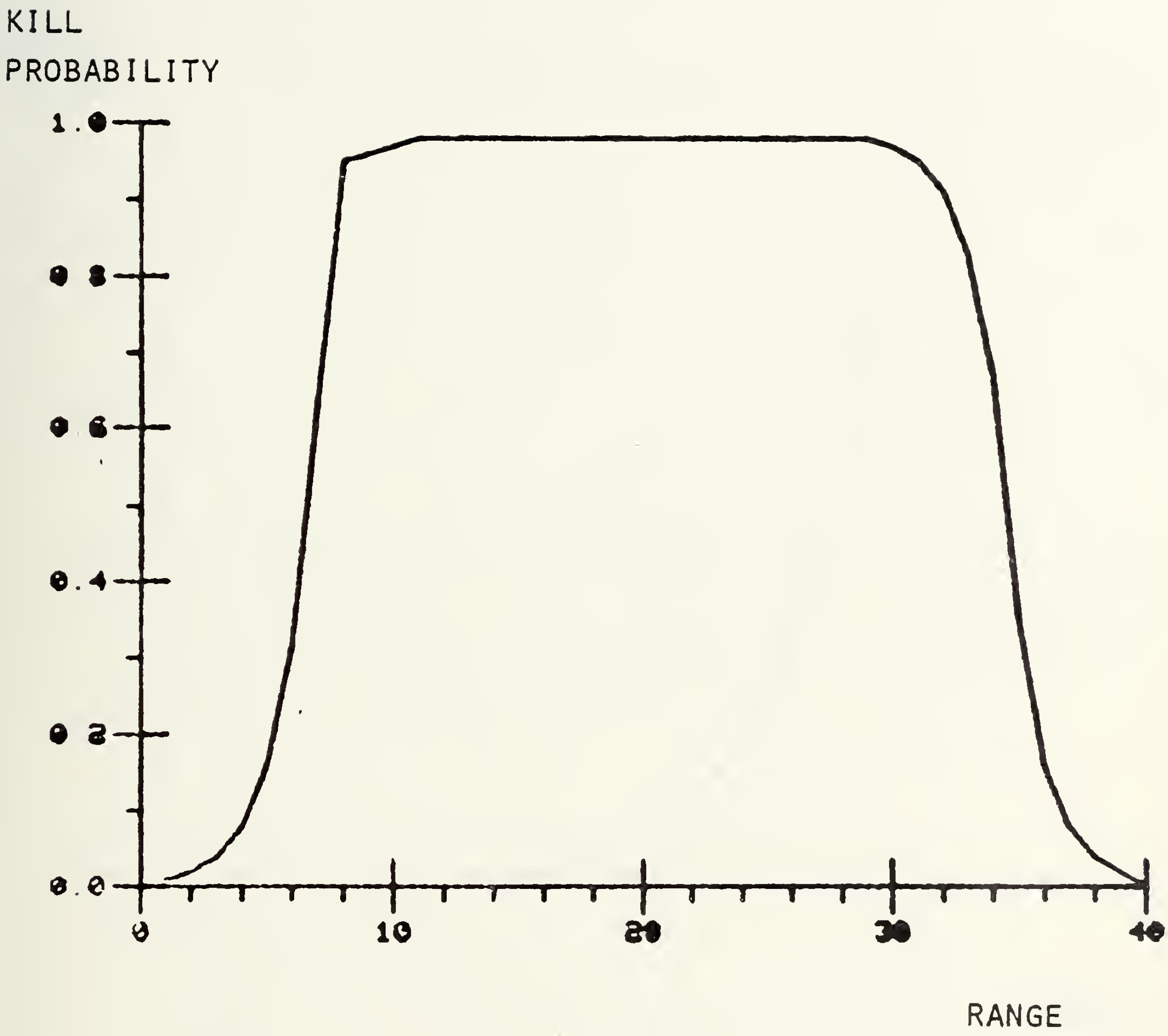

Figure 2 - PROBABILITY OF A KILL BY A HOSTILE WEAPON VS. THE RANGE OF THE TARGET AIRCRAFT FROM THE WEAPON LAUNCH SITE.

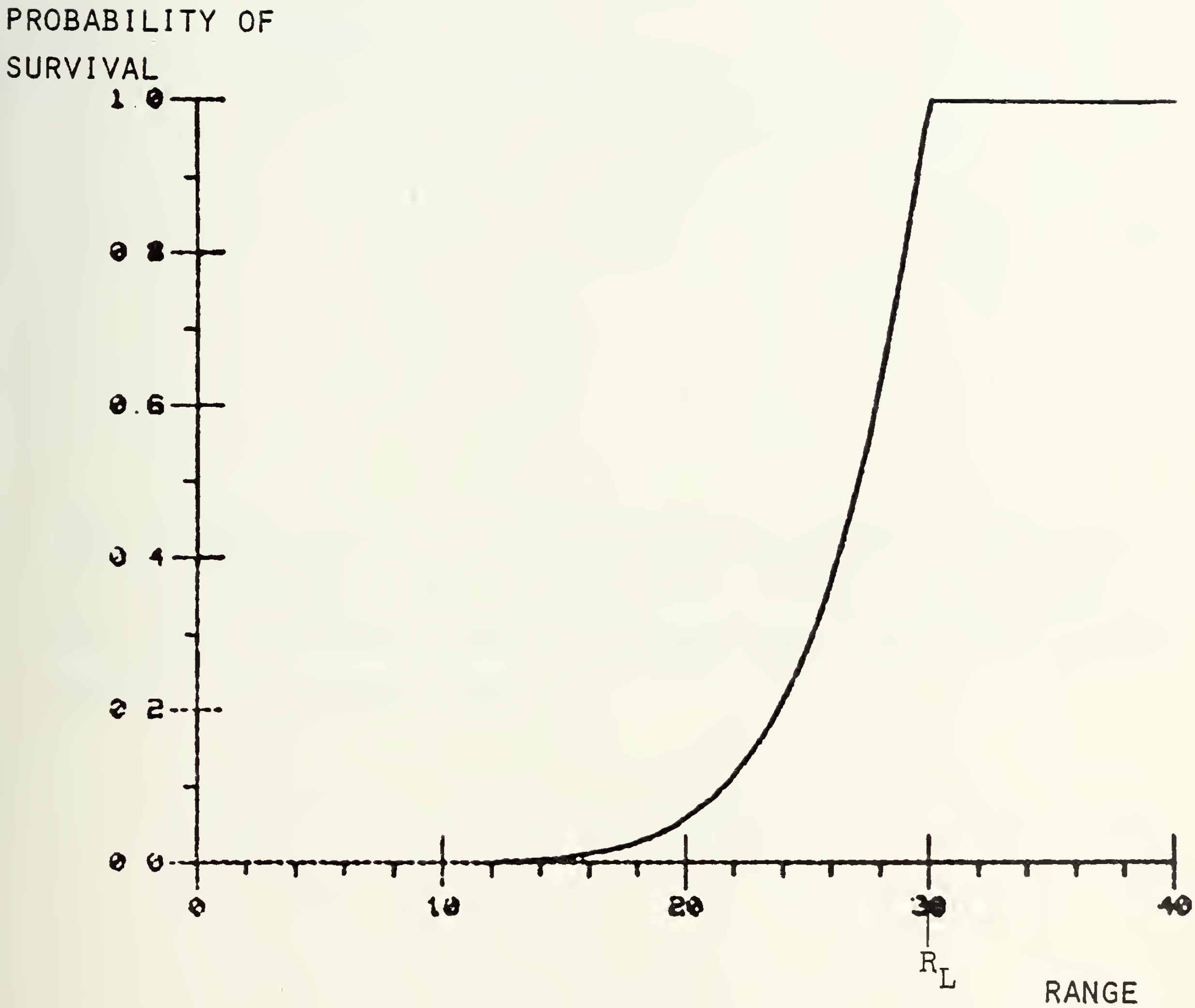

Figure 3 - ASSUMED PROBABILITY OF SURVIVAL AGAINST A HOSTILE WEAPON VS. THE RANGE FROM THE WEAPON SITE.

The exposure, or probability of kill, becomes:

$$\begin{aligned} \text{EXPOSURE} &= \text{P(KILL)} \\ &= 1 - \text{P(SURVIVAL)} \\ &= 1 - \left(\frac{r}{R_L}\right)^n \end{aligned} \qquad (2)$$

Fig 4 shows a plot of the calculated exposure superimposed on the typical kill probability curve. The factor n is selected to give the best fit between the two curves in the area of the greater range.

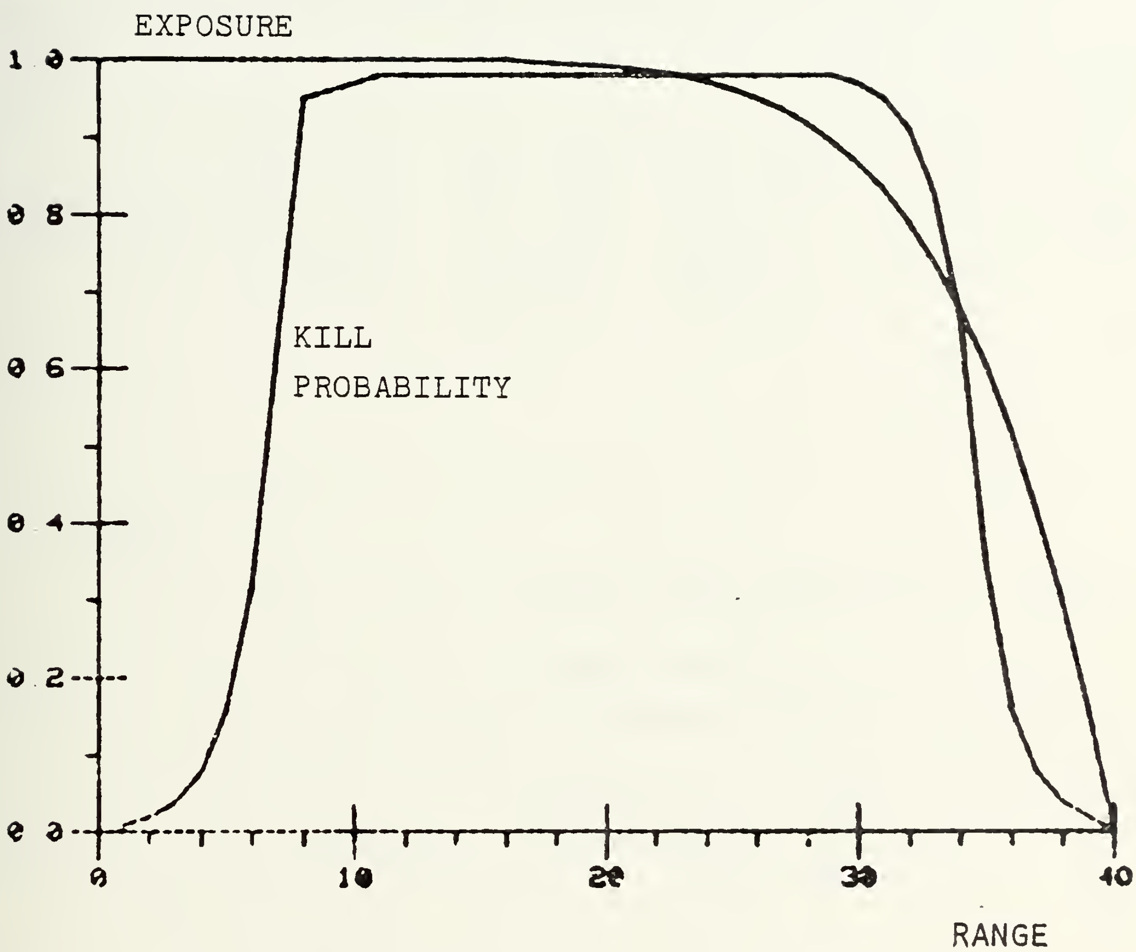

Figure 4 - EXPOSURE TO AND KILL PROBABILITY OF A HOSTILE WEAPON VS. THE RANGE FROM THE WEAPON LAUNCH SITE.

There will be some areas where the aircraft could be within lethal range of multiple weapons systems. In this case, the assumption was made that the probabilities of survival against the individual weapons were independent of each other. The overall survival probability then becomes the product of the individual probabilities given by:

$$P(\text{SURVIVAL}) = \left(\frac{r_1}{R_{L1}}\right)^{n_1} \left(\frac{r_2}{R_{L2}}\right)^{n_2} \left(\frac{r_3}{R_{L3}}\right)^{n_3} \cdots \qquad (3)$$

Where:

r_1, r_2, r_3 = Range from emitters 1, 2, and 3 respectively

R_{L1}, R_{L2}, R_{L3} = Maximum lethal range of weapons 1, 2, and 3 respectively

n_1, n_2, n_3 = Stored emitter parameters

The exposure is again equal to:

$$\text{EXPOSURE} = 1 - P(\text{SURVIVAL})$$

$$= 1 - \left[\left(\frac{r_1}{R_{L1}}\right)^{n_1} \left(\frac{r_2}{R_{L2}}\right)^{n_2} \left(\frac{r_3}{R_{L3}}\right)^{n_3} \cdots\right] \qquad (4)$$

If more threat ranges are penetrated, the exposure will more rapidly approach unity.

A subroutine calculates the exposure for each point in the operating area. If it exceeds the pucker factor then that particular point is thrown out as a possible location for the jammer platform. The routine then deletes points which might have a tolerable exposure but are surrounded by points of higher exposure and therefore inaccessable. The points which remain are returned to the main program as possible route points. If a pucker factor of one is input, then it can be expected that a route close to an escort will be generated, and likewise, a pucker factor of zero will generate a pure stand off route.

B. PRIORITIZATION OF EMITTERS

The next step in determining an ECM route is the prioritization of the emitters. This calculation must be performed for each point in the strike group route. The priority should be zero when the strike group is outside the maximum radar detection range and maximum when the strike passes over the radar. For ease of calculation, a model similar to the exposure model was chosen and is given below.

$$\text{PRIORITY} = P_{max}\left[1 - \left(\frac{r}{R_{max}}\right)^{n}\right] \qquad (5)$$

Where:

P_{max} = maximum priority

R_{max} = maximum detection range

n = stored emitter parameter

The parameter n is again stored in the parameter table and determines how the priority will roll off as the range approaches R_{max}. Examples of priority vs. range are plotted in Fig 5 for n = 2, 3, and 4.

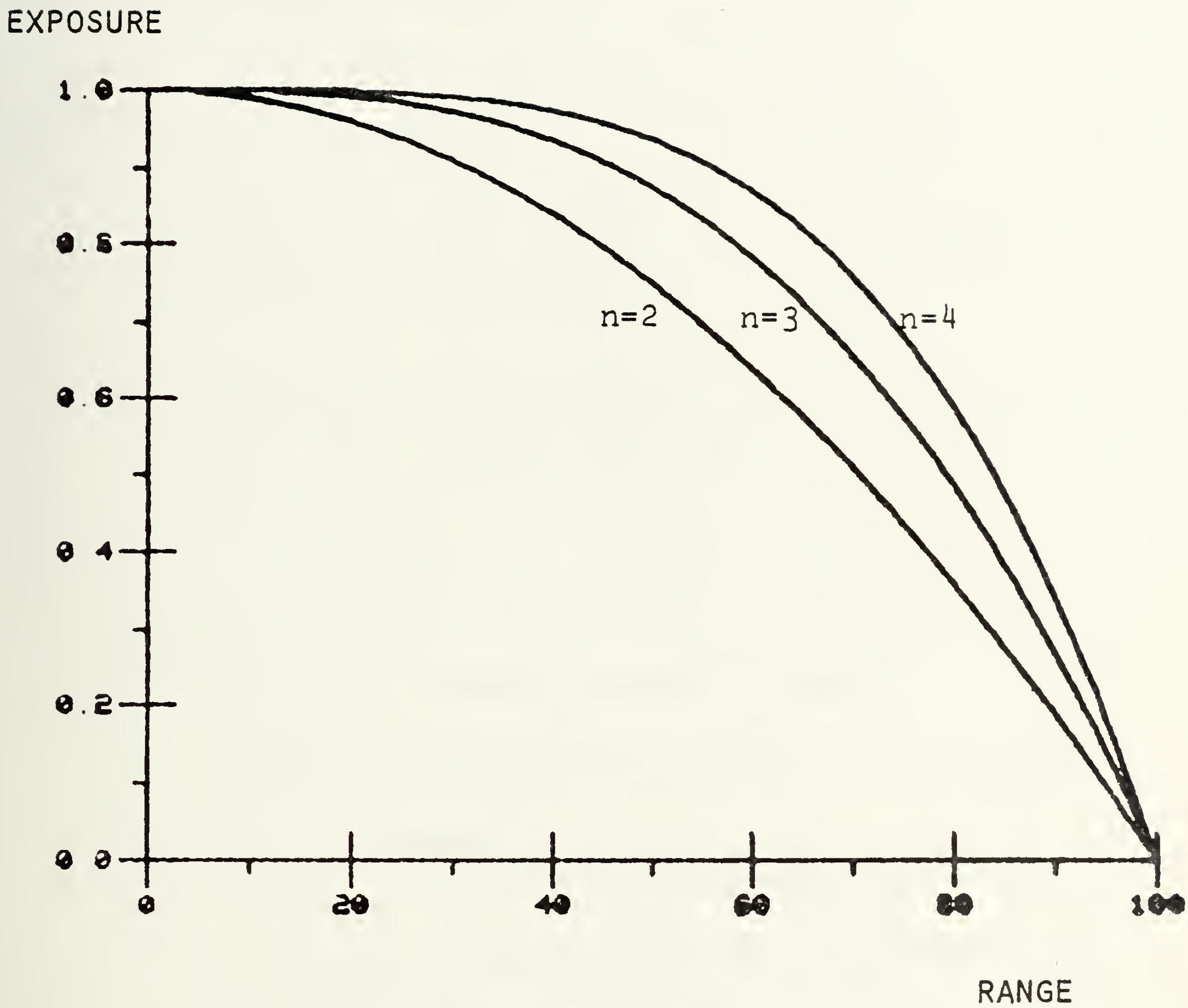

Figure 5 - EXAMPLES OF PRIORITY ASSIGNED TO EMITTERS VS. THE RANGE FROM THE EMITTERS FOR DIFFERENT VALUES OF n.

For radars which control weapons systems, there is a second significant range to consider, that of the maximum lethal range of the associated weapon. The priority of these terminal threat radars is adjusted for distances within this range as below.

$$
\begin{aligned}
\text{PRIORITY} &= 0 && r > R_{max} \\
&= P_{max}\left[1 - \left(\frac{r}{R_{max}}\right)^{n}\right] && R_L < r < R_{max} \\
&= P'_{max}\left[1 - \left(\frac{r}{R_L}\right)^{m}\right] + P_{max} && 0 < r < R_L
\end{aligned}
\qquad (6)
$$

Where:

R_{max} = Maximum detection range

R_L = Maximum lethal range of associated weapon

P_{max} = Maximum priority when outside R_L

P'_{max} = Maximum increase in priority when within R_L

m = Stored emitter parameter

n = Stored emitter parameter

Once again m is a characteristic of the associated weapon and determines how the priority will roll off as the range approaches the maximum lethal range. This factor in addition

to P_{max}, P'_{max}, R_{max}, and R_L are stored in a radar parameter table. An example of a typical priority vs. range is plotted in Fig 6 for n = 5, m = 6, R_{max} = 60, R_L = 30, P_{max} = 0.3, and P'_{max} = 0.6.

The sum of the two terms p_{max} and p'_{max} will not exceed one so the priorities will already be normalized. The resultant priority is then indicative of the degree of threat posed by a particular radar at a given range. Fig 7 is a plot of the normalized priority vs. range of three typical radars, a missile control, a gun control, and an acquisition . If all three of these radars were co-located, it can be seen that as the range decreases from one hundred miles to zero, the acquisition starts out as the highest priority and is surpassed by the missile radar as range decreases, and this priority is surpassed by the anti-aircraft artillery (AAA) radar as the lethal gun range is penetrated.

This prioritization scheme is relatively simple and is only a function of range. The constants P_{max}, P'_{max}, n, and m, which are stored can be changed if desired to alter the priority relationships. For the EW/ACQ radars, the value of R_L stored is zero , indicating an associated weapon with zero lethal range; i.e., no directly associated weapon.

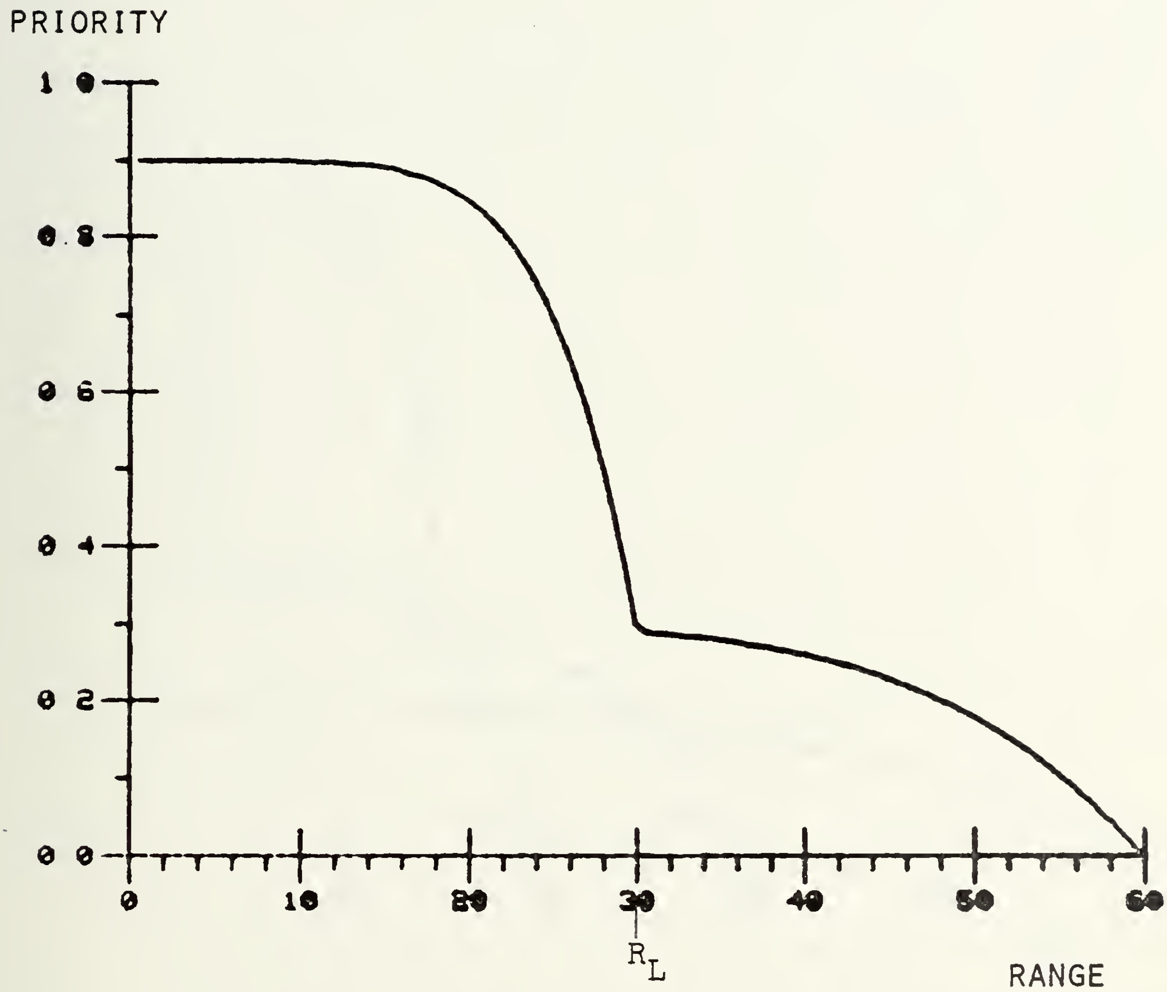

Figure 6 - TERMINAL THREAT RADAR PRIORITY ASSIGNED VS. THE RANGE FROM THE RADAR SITE.

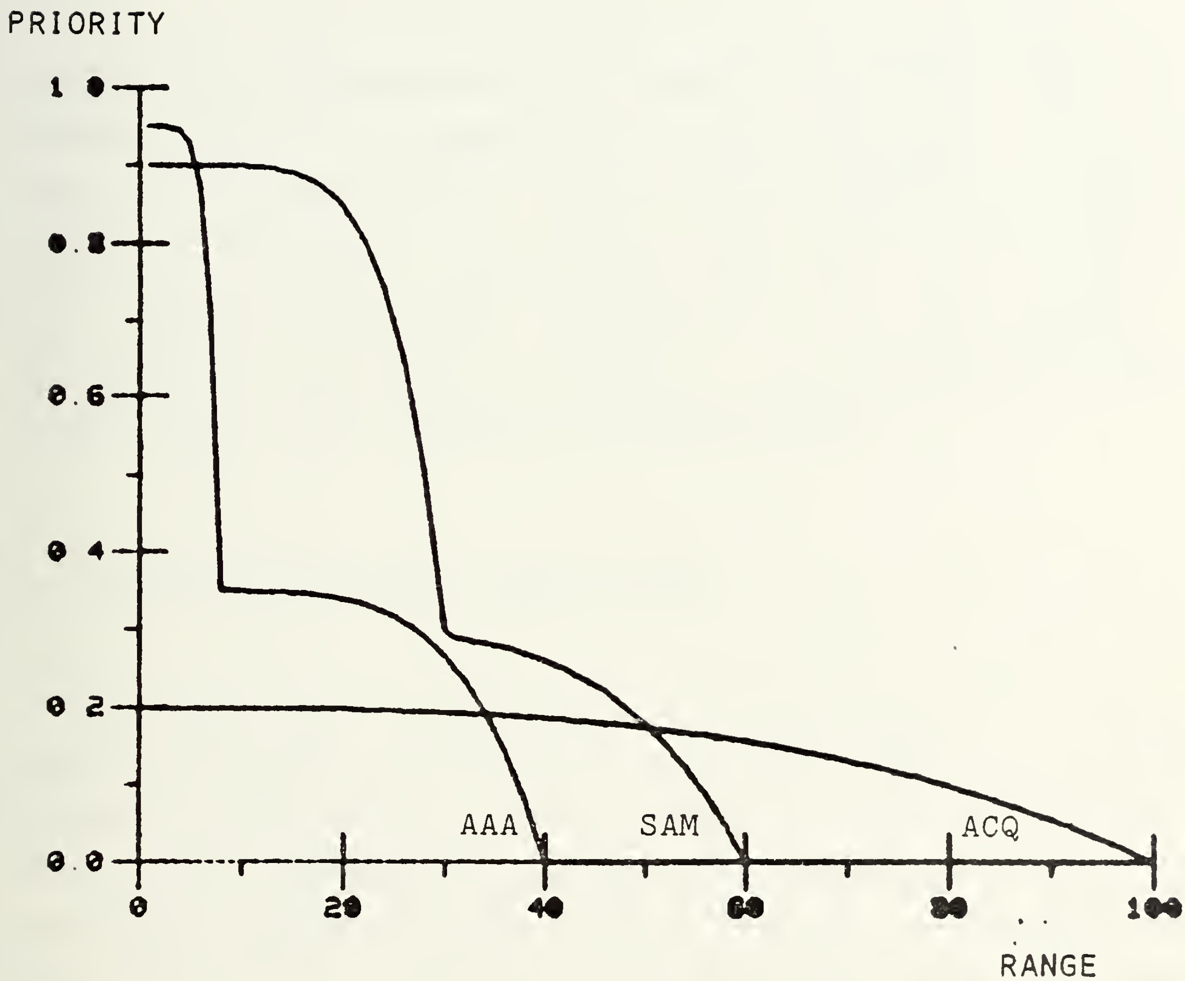

Figure 7 - EXAMPLES OF RELATIVE VALUES OF SAM, AAA, AND ACQ PRIORITY VS. THE RANGE FROM THE RESPECTIVE SITE.

III. JAMMING EFFECTIVENESS DETERMINATION

To determine an optimum route by any method requires a measure of performance for the jammer platform. Given a strike group to protect at any instant of time against an enemy air defense network, with an ECM aircraft of fixed jammer configuration, an operator must have some factor by which he can compare possible locations for his aircraft. The performance measure utilized in this program was a jam-to-signal power ratio weighted by the respective emitter priority and jammer modulation vulnerability.

A. JAM-TO-SIGNAL RATIO CALCULATION

The ratio of jammer power at the receiver to the received signal power (J/S) provides a good performance measure for a jammer. Since the jammer is fixed in power, if the J/S is computed for the different possible positions of the jammer platform, it will give a relative indication of the effectiveness against that particular radar from each point in the area. The formula [Ref. 2] used for the J/S in the program is given below.

$$\frac{J}{S} = \frac{4\,\pi\,P_j\,B\,G_{jr}\,G_{rj}\,R_t^4\,g_j^2}{P_r\,G_{rt}^2\,\sigma\,R_j^2\,g_t^4} \qquad (7)$$

Where:

P_j = Jammer power (Watts/MHz)

B = Victim radar noise bandwidth (MHz)

G_{jr} = Jammer antenna gain

G_{rj} = Radar antenna gain toward jammer

R_t = Strike group range (meters)

g_j = Radar-to-target propagation factor

P_r = Radar power (Watts)

G_{rt} = Maximum radar antenna gain

σ = Strike group cross section (square meters)

R_j = Jammer range (meters)

g_j = Radar-to-jammer propagation factor

All the values in this expression are readily available from stored tables or intermediate calculations with the exception of G_{rj}, the gain of the radar in the direction of the jammer platform.

Although the antenna patterns for all hostile emitters are not available, estimates of the maximum gain, beamwidth, maximum side lobe level, and average side lobe level are available from various sources. With this information it is possible to approximate an antenna aperture dimension and an Nth order cosine electric field aperture distribution [Ref. 3]. Given the aperture distribution and dimension, the side lobes in the proximity of the main lobe can be determined.

To simplify the calculations, it was assumed in the program that terminal threat radars would have uniform (zero order cosine) aperture distributions and EW/ACQ radars would

have first order cosine distributions. The half power beamwidths for each case are stored in the parameter table and can be used with wavelength to determine the aperture dimension a as given below.

THREAT RADAR:

$$a = \frac{51\ \lambda}{B} \qquad (8A)$$

EW/ACQ RADAR:

$$a = \frac{69\ \lambda}{B} \qquad (8B)$$

WHERE:

B = Half power beamwidth ($^{\circ}$)

λ = wavelength (m.)

a = Aperture dimension (m.)

Knowing a, the normalized radation pattern for both cases can be determined from the following formulas.

THREAT RADAR:

$$E(\Phi) = \frac{SIN(\Psi)}{\Psi} \qquad (9A)$$

EW/ACQ RADARS:

$$E(\Phi) = \frac{\Pi}{4}\left[\frac{\mathrm{SIN}\left(\Psi + \frac{\Pi}{2}\right)}{\Psi + \frac{\Pi}{2}} + \frac{\mathrm{SIN}\left(\Psi - \frac{\Pi}{2}\right)}{\Psi - \frac{\Pi}{2}}\right] \qquad (9B)$$

WHERE:

$$\Psi = \Pi\left(\frac{a}{\lambda}\right)\ \mathrm{SIN}(\Phi)$$

E = Far-field electric field intensity

Φ = Azimuth

Since these expressions represent normalized patterns, they have to be multiplied by the maximum gain which is also stored in the parameter table to obtain absolute patterns. From these patterns, the program computes each side lobe level and sets the pattern equal to that level across the entire lobe to eliminate the narrow nulls. When the side lobes fall below the average side lobe level, which is a stored table value, the remainder of the pattern is set equal to this average level.

Only the maximum gain, beamwidth, average side lobe level, frequency, and EW/ACQ or terminal threat designation therefore need to be known to generate a radiation pattern approximation. Fig 8 shows an ACQ and Fig 9 a terminal threat pattern generated by this procedure. As would be expected, the ACQ radar has low side levels but it pays for this with a lower gain and wider main beam. The terminal threat radar pattern has a narrower main beam and higher gain but the side lobe levels are higher.

With the pattern information to provide an approximation

of the radar antenna gain when the actual value is unavailable, the J/S can be computed from every allowable jammer position in the operating area.

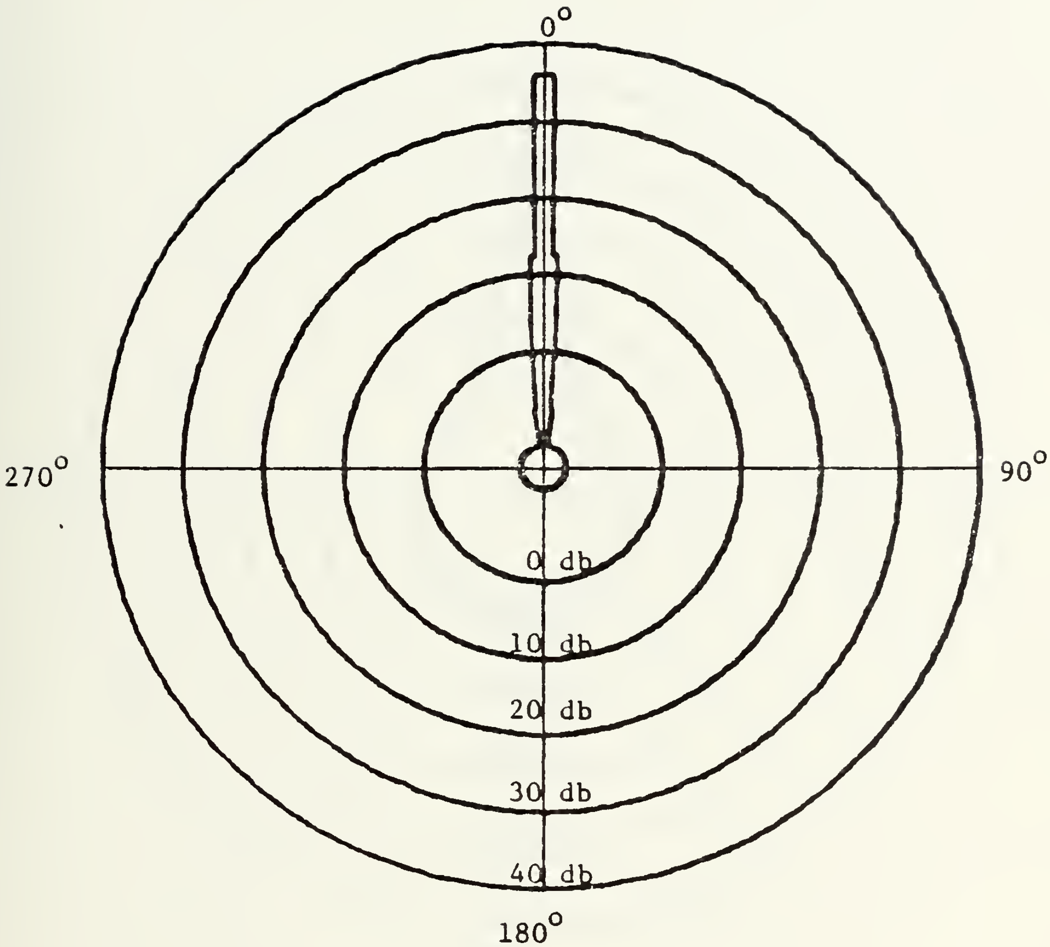

Figure 8 - APPROXIMATED ACQ RADAR PATTERN WHERE GAIN = 36 DB, BEAMWIDTH = 1.5°, AND SIDE LOBE LEVEL = -10 DB.

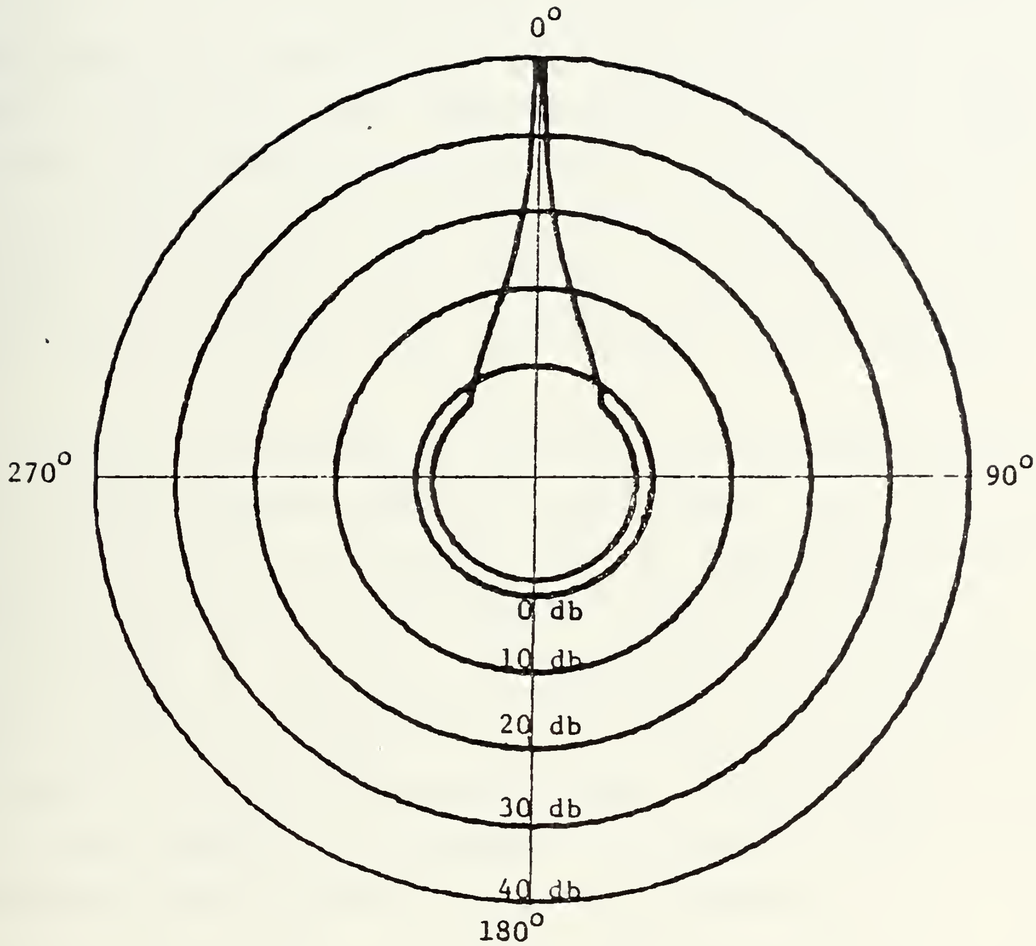

Figure 9 - APPROXIMATED THREAT RADAR PATTERN WHERE GAIN = 40 DB, BEAMWIDTH = 0.8°, AND AVERAGE SIDE LOBE LEVEL = -2 DB.

B. POWER MANAGEMENT SCHEME

An ECM aircraft is limited in the number of jammers it can carry. In a moderately dense environment there will be cases when all radars cannot be jammed. The power management scheme determines the assignments and for this program it was made very straightforward. Since a priority is computed for each radar, the available jammers are assigned on a one to one basis against the radars in descending order of priority. Therefore, the J/S is computed only against those higher priority radars for which jammers are available.

It may be possible to increase the jammer bandwidth to cover multiple signals with a single jammer but the power per MHz would be reduced and the overall effectiveness lessened. With the power management scheme utilized, if all the jammers in a band are assigned, the lower priority radars simply go uncountered. This policy makes possible the generation of a new EOB of uncoverable signals. This EOB can be run with a second aircraft of lower pucker factor through the same program to generate two mission routes without unnecessary duplication of jammer assignments.

C. OVERALL EFFECTIVENESS

The J/S varies over a wide range and can easily be as low as 10^{-6} or as high as 10^{6}. Excessively high values of the J/S beyond that necessary for maximum degradation of the victim radar would be wasteful of jammer power and therefore not desired. Likewise , extermely low values of J/S would

essentially be useless against a radar and would likely waste a jammer asset which could be more useful elsewhere. The program therefore converts the J/S to db and limits it to a -25 db to +50 db range and normalizes this range. The range can be altered to reflect any desired values of minimum and maximum values for an effective J/S. The J/S figures are then multiplied by their respective priorities and jammer modulation vulnerabilities to give a weighted performance indicator for the ECM aircraft against particular radars. The modulation vulnerability is a stored table parameter associated with each emitter. It is determined experimentally and is referenced to unity being the effect of noise jamming only.

The weighted performances are then summed for all the radars that can be jammed to give a total performance factor for a particular point in the operating area. A high value for this number indicates that the high priority signals are being jammed by a high J/S with an effective jammer modulation.

D. SAMPLE EFFECTIVENESS CALCULATIONS

As an example of some of the numerical values encountered in these calculations, consider a simple static situation where there are a SAM and ACQ radar co-located at latitude 30°30' and longitude 90°30'. If a strike aircraft with cross-section of nine square meters is located at latitude 30°20' and longitude 90°20', the jammer performance for a given test point latitude 30°10' and longitude 90°10' would be calculated as follows.

First the exposure of the ECM aircraft would have to be determined for the test point to see whether it is

acceptable. The strike group range would be 13.22 nm. and the jammer range would be 26.44 nm. Since there is only one direct threat, the SAM radar, the exposure would be calculated from equation (2) where the values of the table constants are as specified below.

$$\text{EXPOSURE} = 1 - \left(\frac{r}{R_L}\right)^n$$

$$= 1 - \left(\frac{26.44}{30.00}\right)^5$$

$$= 0.468$$

Where:

$R_L = 30.0$ nm

$n = 5$

If the maximum exposure to the ECM aircraft were 0.5, this point would be an allowable jammer position.

The next step would be to determine the priorities of each radar for the given strike position. For the ACQ radar using equation (5) the priority is determined below for the specified table constants.

$$\text{PRIORITY} = P_{max}\left[1 - \left(\frac{r}{R_{max}}\right)^{n}\right]$$

$$= 0.2\left[1 - \left(\frac{13.22}{100.0}\right)^{3}\right]$$

$$= 0.1995$$

Where:

$P_{max} = 0.2$

$R_{max} = 100.0$ nm

$n = 3$

The SAM priority is determined likewise from equation (6) with the range between zero and the maximum lethal range as seen below.

$$\text{PRIORITY} = P'_{max}\left[1 - \left(\frac{r}{R_L}\right)^{m}\right] + P_{max}$$

$$= 0.6\left[1 - \left(\frac{13.22}{30.00}\right)^{6}\right] + 0.3$$

$$= 0.8956$$

Where:

$P'_{max} = 0.6$

$R_L = 30.0$ nm.

$m = 6$

$P_{max} = 0.3$

If the ECM aircraft carries two jammers with frequency coverage such that one can cover the SAM radar while the other covers the ACQ radar, the total jamming performance can be computed for the test point. Using equation (7), the J/S can be computed for each radar as seen below for the specified radar and jammer parameters. The problem is simplified since perfect radar-strike-jammer alignment is attained at the test point. For the ACQ radar the J/S is computed as follows.

$$\frac{J}{S} = \frac{4\pi P_j B G_{jr} G_{rj} R_t^4 g_j^2}{P_r G_{rt}^2 \sigma R_j^2 g_t^4}$$

$$= 105.12$$

$$= 40.44 \text{ db.}$$

Where:

$P_j = 200.0$ W/MHz

$B = 1.0$ MHz

$G_{jr} = 10.0$ db

$G_{rj} = 36.0$ db

$R_t = 13.22$ nm

$g_j = g_t = 1.0$

$P_r = 1.0$ Mw

$G_{rt} = 36.0$ db

$\sigma = 9.0\ m^2$

$R_j = 26.44$ nm

For the SAM radar the J/S is similarly determined.

$$\frac{J}{S} = 55.80$$

$$= 34.94 \text{ db.}$$

Where:

$P_j = 200.0$ W/MHz

$B = 0.8$ MHz

$G_{jr} = 10.0$ db

$G_{rj} = 40.0$ db

$R_t = 13.22$ nm

$g_j = g_t = 1.0$

$P_r = 600.0$ Kw

$G_{rt} = 40.0$ db

$\sigma = 9.0\ m^2$

$R_j = 26.44$ nm

These J/S values are then limited if they do not fall in the -25 db to +50 db range and then normalized. For the ACQ and SAM radars the normalized effectivenesses are adjusted as below.

$$\frac{J}{S}\ \text{NORMALIZED} = \frac{\left[\dfrac{\left(\frac{J}{S}\right)}{50.0}\right] + 0.5}{1.5}$$

ACQ:

$$\frac{J}{S}\ \text{NORMALIZED} = 0.8725$$

SAM:

$$\frac{J}{S}\ \text{NORMALIZED} = 0.7992$$

If both jammers use complex modulations which have been determined to be twice as effective as Gaussian noise jamming , the J/S values are weighted by this modulation vulnerability factor of two. The J/S is also weighted by the corresponding emitter priority computed previously to give a performance indication as shown below.

$$\text{PERFORMANCE} = \left(\frac{J}{S}\right)(\text{MODULATION VULNERABILITY})(\text{PRIORITY})$$

$$\text{ACQ PERFORMANCE} = (0.8724)(2.0)(0.1995) = 0.3481$$

$$\text{SAM PERFORMANCE} = (0.7991)(2.0)(0.8956) = 1.4313$$

The performances against the individual radars are summed for a total performance measure for this test point.

$$\begin{aligned}\text{TOTAL PERFORMANCE} &= \text{ACQ PERFORMANCE} + \text{SAM PERFORMANCE}\\ &= 0.3481 + 1.4313\\ &= 1.7794\end{aligned}$$

This performance becomes the MOE for this test point. The MOE is used as a comparison between the different test points to determine the best position to designate as an ECM route point.

IV. ROUTE DETERMINATION

A. THE OPTIMUM ROUTE

The problem of determining an optimum route can most readily be determined in a case such as this through a dynamic programming approach [ref. 1]. By starting at the desired final position of the ECM aircraft, one could compute positions of high performance and by iterating back in time and retaining the optimum routes eventually come up with the optimum route which maximizes the total ECM performance. The problem encountered however is the execution time and machine size required for such a solution. For example, in a one hundred nautical mile square area in which a resolution to the nearest nautical mile in both dimensions is desired, there are ten thousand possible ECM aircraft locations. If there are thirty points in the strike route and an EOB of fifty emitters there could be fifteen million effectiveness values to be computed, Because of the flight speed constraint on the ECM aircraft, many of these results would eventually be discarded in the route determination. If the parameters of each emitter must be stored in an external device and read for each calculation, it is obvious that the time of execution will exceed that available to the aircrew.

B. ROUTE GENERATION

There are some peculiarities to the ECM route problem which allow a high performance route close to the optimum to be computed in much less time. First, the strike route will generally be planned to minimize exposure and will usually have a distinct maximum as the strike passes over the area of the target. The exposure will typically increase monotonically to this maximum and decrease in the same manner. The total priority (sum of the individual emitter priorities for a particular strike group point) will be indicative of the strike group exposure and thus reach a maximum at this same point as seen in Fig 10. Since the performance is weighted by this priority the optimum ECM route can be expected to pass through the point where performance is maximum for this particular time. This time can be determined from the priorities previously computed. All possible jammer locations for this time slot can then be checked and the ten positions of highest performance retained as possible ECM route points.

Because the total priorities decrease monotonically for strike points either side of the highest priority point, the total performances at earlier and later optimum ECM route points can be expected to decrease in the same manner since they again are weighted by the priorities. As a result, it is not necessary to look at all possible jammer locations for the next route point, only those within the one time unit ECM aircraft flight distance from the previous point. For a well defined strike exposure maximum, this is the path the optimum route would be expected to follow. This will significantly reduce the execution time and required storage space. The time unit between successive route points must be large enough so that a distinct maximum performance point can be determined but not so large as to overlook significant interim high performance points or to overfly large areas of non-allowable positions. For this program a one minute time space between route points was used.

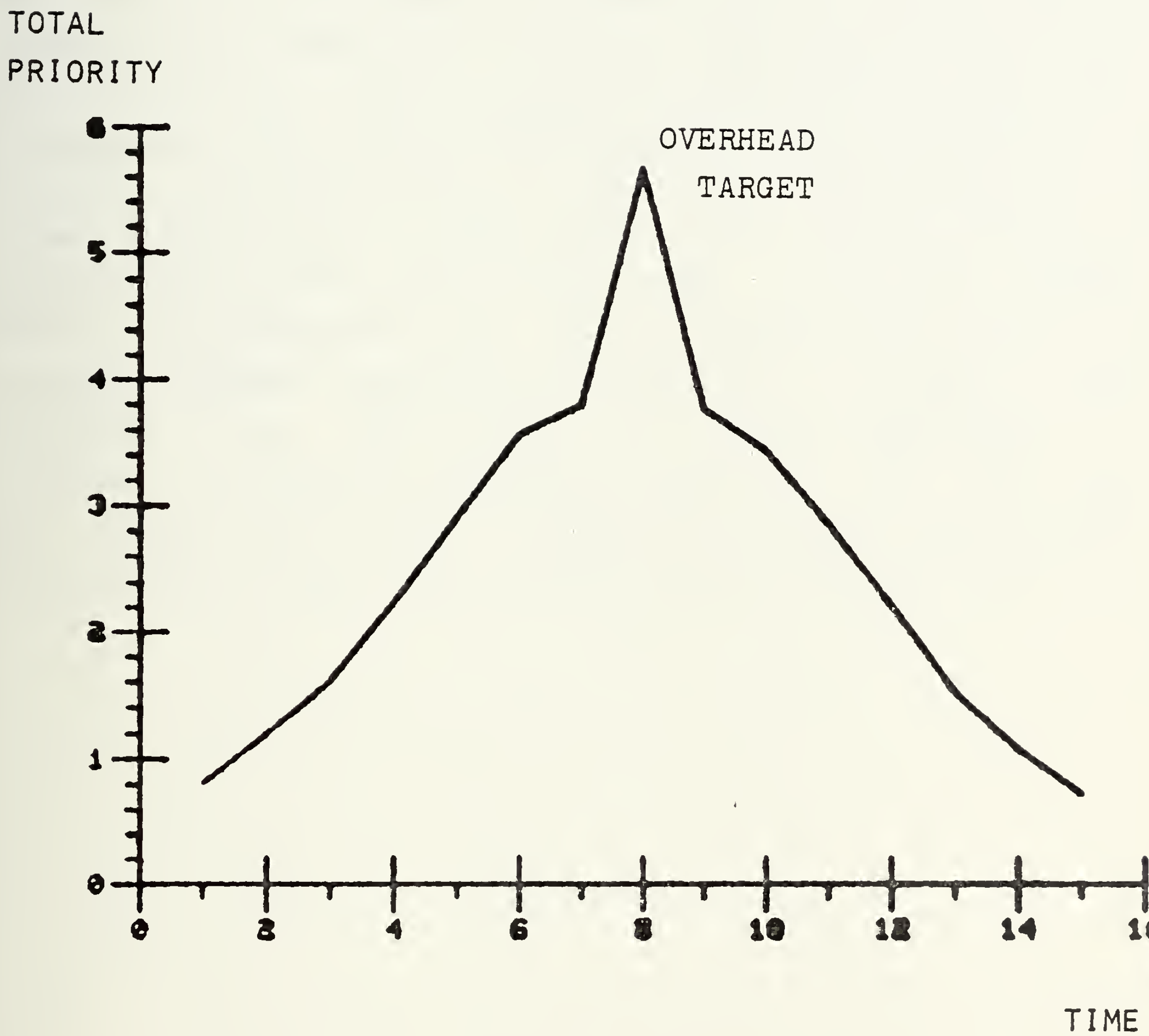

Figure 10 - STRIKE GROUP EXPOSURE (TOTAL PRIORITY AT EACH POINT) VS. TIME.

Starting with the highest strike group priority point the ECM route can be generated in two segments by iterating away from this point toward the start and finish strike group points. For each iteration, the ECM route point is determined as the highest performance point within the one minute ECM aircraft flight distance from the preceding route point as seen in Fig 11. When all these points have been calculated, the two high performance route segments to and from the optimized point are connected to form a route. The total performance at each point in the route is summed and associated with the route as its MOE. For this program, when the performance is being computed from each of the allowable jammer locations for the time of highest strike exposure, the ten points of highest performance are retained. A route is computed for each of the ten points and output with its MOE. Usually the first route will have the highest MOE but the operator has his choice of the ten.

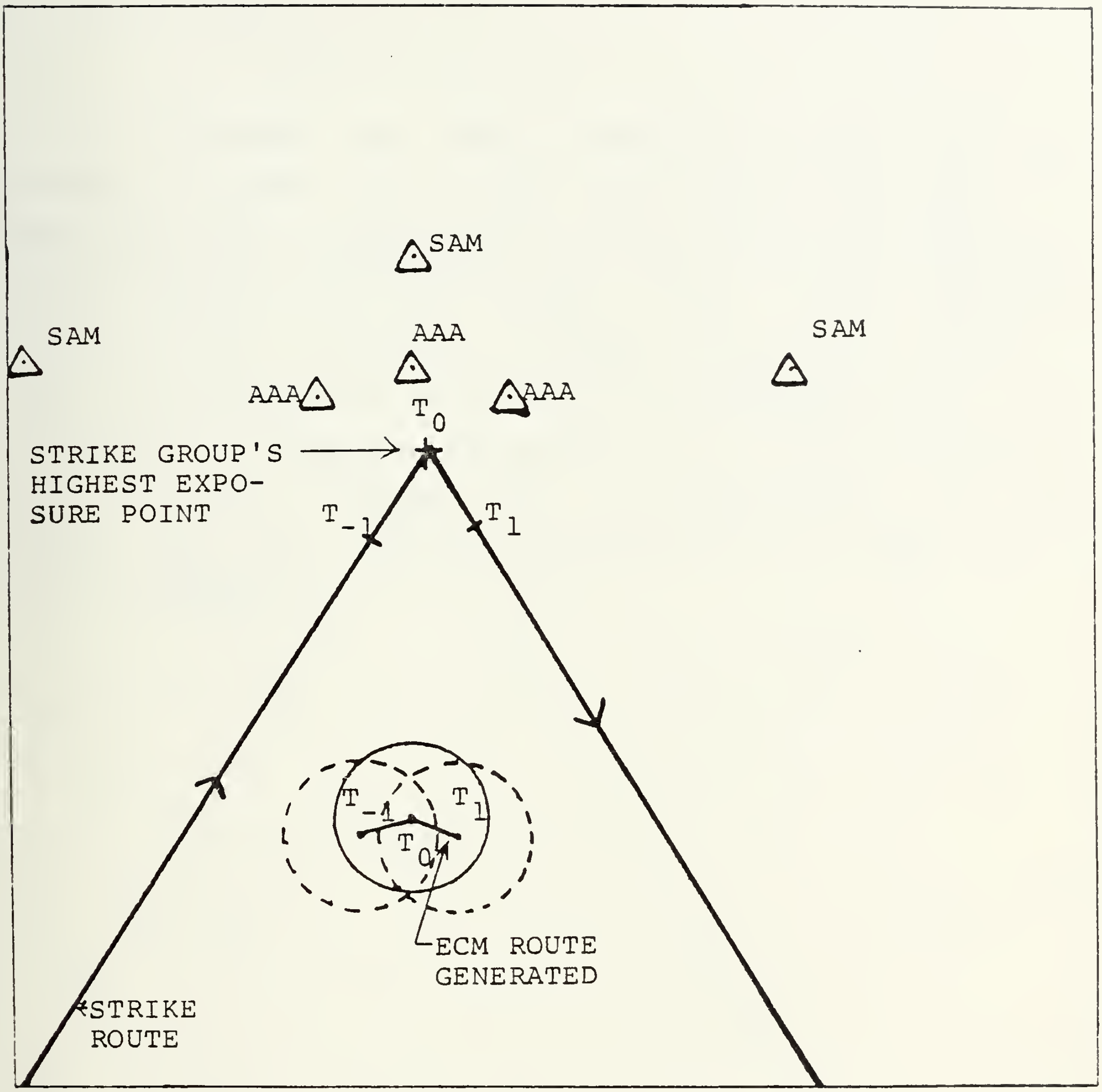

Figure 11 - ECM ROUTE GENERATION BY ITERATING FORWARD AND BACKWARD IN TIME FROM THE OPTIMUM ECM ROUTE POINT AT T_0.

C. SAMPLE ROUTE

To illustrate the route generated by the program, consider a simple EOB of one acquisition, three SAM, and three AAA radars. The operating area will be considered a square bounded by latitude 00° 00' and 01° 30' and longitude 00° 00' and 01° 30'. The strike route, threat emitter locations and maximum lethal ranges are seen in Fig 12, a blow up of the area of interest in the operating area. The ECM routes for maximum exposures of 0.0, 0.9, and 0.99 are seen in Fig 13 through Fig 15 respectively. If the exposure is set to 1.0, then as expected an escort route will be generated.

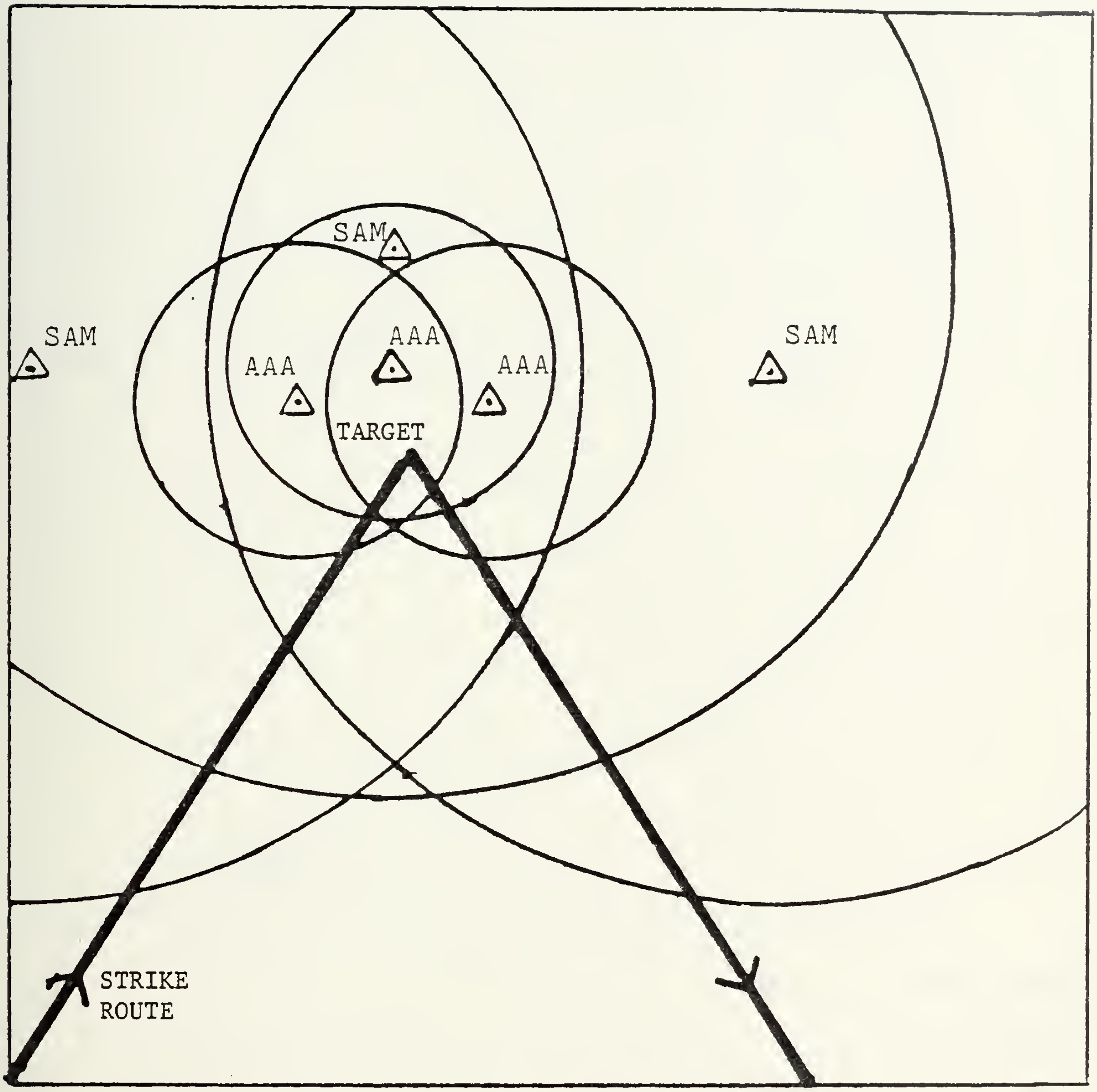

Figure 12 - SAMPLE STRIKE ROUTE AND EOB WITH MAXIMUM LETHAL RANGES OF WEAPONS ASSOCIATED WITH THE EMITTERS.

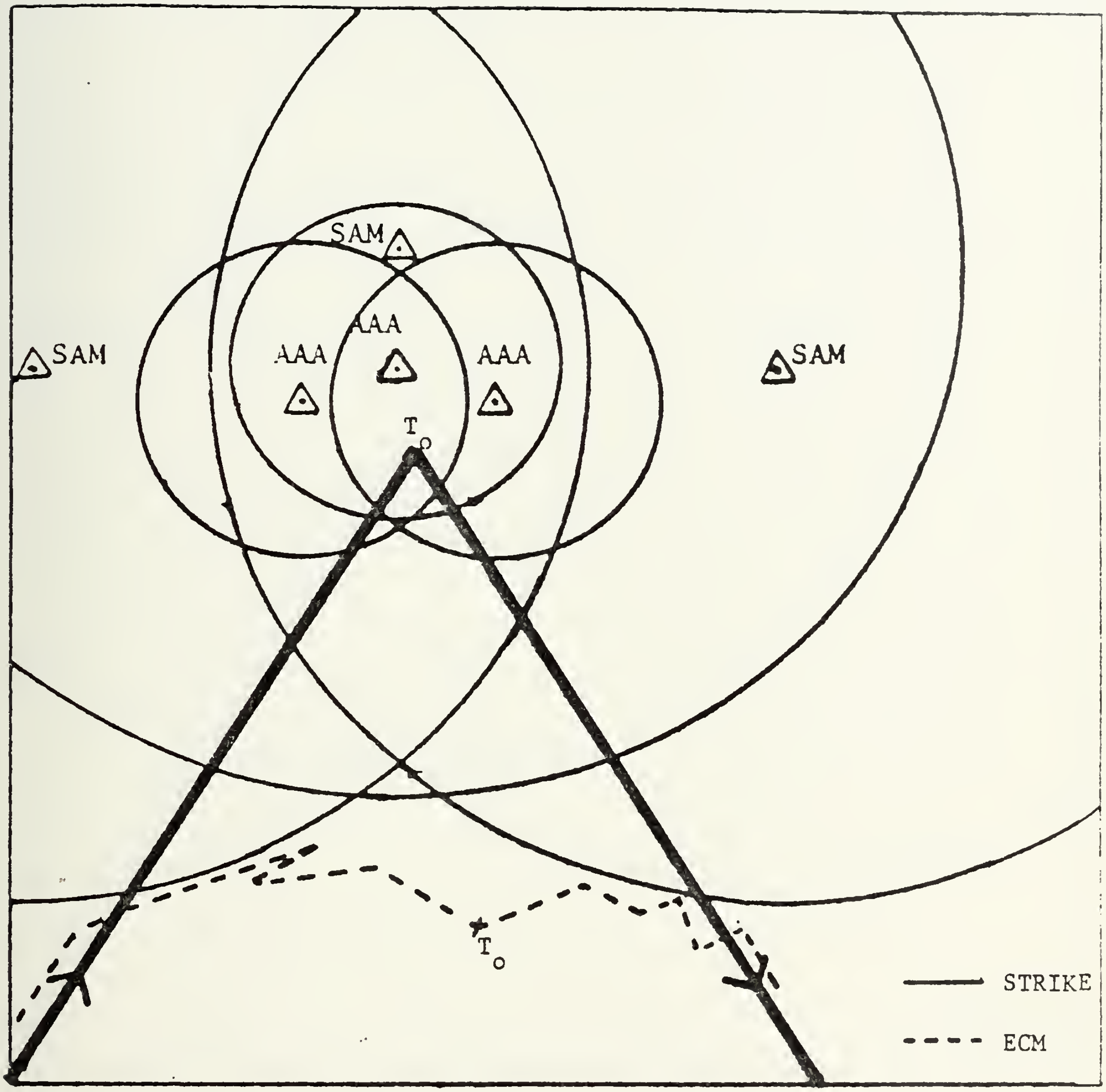

Figure 13 - ECM ROUTE GENERATED WHEN MAXIMUM EXPOSURE =0.0.

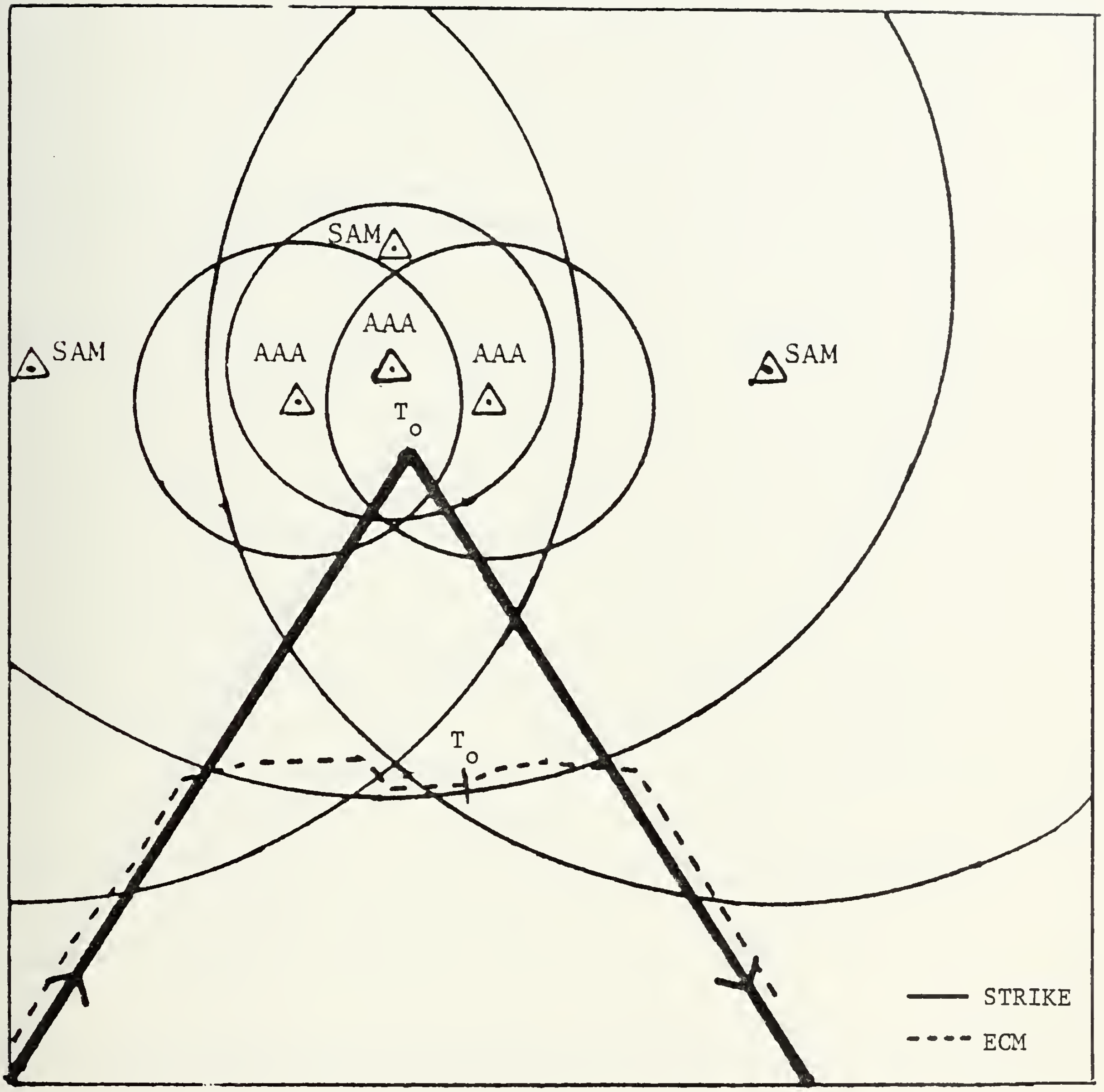

Figure 14 - ECM ROUTE GENERATED WHEN MAXIMUM EXPOSURE =0.9.

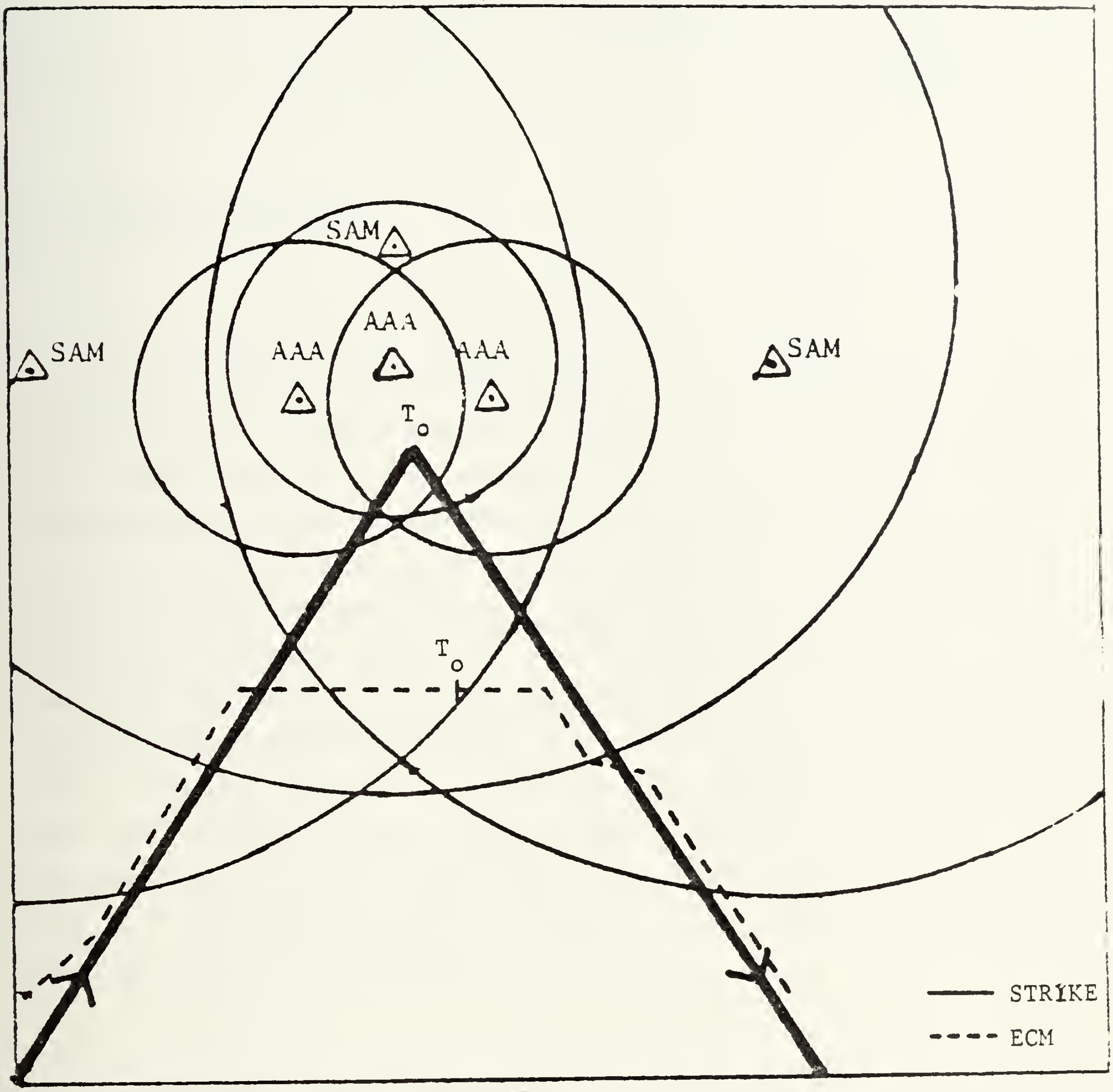

Figure 15 - ECM ROUTE GENERATED WHEN MAXIMUM EXPOSURE =0.99.

V. SUMMARY

A. CURRENT PROGRAM

The program as presented in the preceding sections to determine a route for an ECM aircraft is very simple. In its present form it uses an excessive amount of core storage but only because of the intermediate testing done during its development. In translating to a smaller machine it can be readily compacted to significantly reduce the size required. It must be remembered that the route generated is not the absolute optimum, but a one point optimization with a high performance route to and from this point. For the typical strike route and EOB though, the route should come close to the absolute optimum. The program listing is enclosed at the end of this report. The program was run on the Naval Postgraduate School IBM-360/67 computer under CP/CMS System and for the sample routes generated it took approximately twelve minutes of computer time.

B. SUGGESTIONS FOR IMPROVEMENT

If external storage such as floppy disk is available on the system which incorporates this program, there are several areas where the program performance could be enhanced without a significant increase in size or execution time. The antenna patterns could be pre-computed for all hostile emitters and stored in an external table for simple

lookup of the value needed. If this is done the aperture can be better approximated and a more accurate pattern can be computed since the computation time would not be a factor. The J/S could be weighted by an additional factor indicative of experimental results of jammer effectiveness measurements against known system types. This factor would also be predetermined for each hostile emitter and stored externally as a function of jammer range. In computing the allowable positions for the ECM aircraft within the maximum exposure limits, the computed exposure can be modified to reflect the reduced exposure to the ECM aircraft due to its own jamming. The jamming performance can also be adjusted to indicate increased performance when jammer frequencies and pointing angles overlap. This would possibly require a different jammer management scheme. It would also be easy to observe the total priority as a function of strike group position to determine how it increases to its highest point and then falls off. This characteristic could then be translated to indicate to the operator how far from the optimum the generated route deviates. The final program should be checked with a complete dynamic programming optimization to determine when it becomes unreliable as a planning tool.

```
C     PROGRAM TO DETERMINE AN OPTIMUM ECM ROUTE FOR A
C     JAMMER AIRCRAFT IN SUPPORT OF A GIVEN STRIKE ROUTE
C
C
C
      DIMENSION SLAT(50),SLON(50),SLAT1(50),SLON1(50),SLAT2(50),SLON2(50
     1),RLAT(50),RLON(50),PRTY(50,50),PRTY1(50,50),PRTY2(50,50),NPRTY(50
     2),ELNT1(50),ELNT2(50),JXN(20),F1(10),F2(10),PWR(10),GAN(10),IMITE(
     3100,100),TPRTY(50),GN(180),G(50,180),TOTP(10),ELAT1(50,10),ELON1
     4(50,10),ELAT2(50,10),ELON2(50,10),R1FACT(10),R2FACT(10),LT1(10),
     5LN1(10),RADN1(50),RADN2(50),RMAX(50),RL(50),PMAX(50),PPMAX(50),FM(
     650),FN(50),FREQ(50),RPWR(50),GMAX(50),BEAM(50),AVGSLL(50),ITRAK(50
     7),FMOD(50)
      INTEGER RADN1,RADN2,ELNT1,ELNT2
C     INPUT THE GEOGRAPHICAL LIMITS OF THE OPERATING AREA BY LAT/LON
      READ(3,0100)ALAT,ALON,BLAT,BLON
0100  FORMAT(4F10.2)
C
C
C     INPUT THE NUMBER OF STRIKE ROUTE POINTS(ISTK) AND RADAR CROSS
C     SECTION(CRSCT)
C
      READ(3,0110)ISTK,CRSCT
0110  FORMAT(I3,F10.2)
C
C
C     INPUT THE STRIKE ROUTE AS POINTS SEPARATED BY ONE MINUTE IN TIME
C     BY LAT/LON(SLAT,SLON)
C
      READ(3,0120)(SLAT(I),SLON(I),I=1,ISTK)
0120  FORMAT(2F10.2)
C
C
C     INPUT THE NUMBER OF RADARS IN THE AREA EOB (NTOT) AND THE TOTAL
C     NUMBER OF ENTRIES IN THE ELINT PARAMETER TABLE(NTAB)
C
      READ(5,0130)NTOT,NTAB
0130  FORMAT(2I3)
C
C     INPUT THE AREA EOB BY ELINT NUMBER(ELNT1,ELNT2) AND LAT/LON(RLAT,
C     RLON)
C
      READ(4,0140)(ELNT1(I),ELNT2(I),RLAT(I),RLON(I),I=1,NTOT)
0140  FORMAT(2A4,2F10.2)
C
C     INPUT THE PUCKER FACTOR(PUKR) NUMBER OF JAMMERS(NJAM) AND THE
C     MAXIMUM ONE MINUTE FLIGHT DISTANCE FOR THE ECM AIRCRAFT
      READ(5,0150)PUKR,NJAM,DMAX
```

```
0150  FORMAT(F10.6,I3,F10.6)
C
C
C     INPUT THE ECM ROUTE START POINT BY LAT/LON(CLAT/CLON)
      READ(5,0170)CLAT,CLON
0170  FORMAT(2F10.2)
      LAB=DGMN(CLAT)-DGMN(ALAT)+.1
      LOE=DGMN(CLON)-DGMN(ALON)+.1
C
C     INPUT THE ECM AIRCRAFT JAMMER CONFIGURATION.
C         JXN=0 IF THE JAMMER IS ALREADY IN USE
C             1 IF THE JAMMER IS AVAILABLE (INITIAL SET)
C         F1 = LOW END FREQUENCY (HZ)
C         F2 = HIGH END FREQUENCY (HZ)
C         PWR = JAMMER OUTPUT POWER (W)
C         GAN = JAMMER ANTENNA GAIN (DB)
C
      READ(2,0180) (JXN(I),F1(I),F2(I),PWR(I),GAN(I),I=1,NJAM)
0180  FORMAT(I2,4E16.8)
C
C     CHANGE THE JAMMER FREQUENCIES FROM MHZ. TO HZ.
C
      DO 0181 I=1,NJAM
      F1(I)=F1(I)*100000000.
      F2(I)=F2(I)*100000000.
0181  CONTINUE
C
C     INPUT THE RADAR PARAMETER TABLE
C          RADN1 AND RADN2 = 8 ALPHANUMERIC CHARACTERS FOR ELINT NUMBER
C          RMAX = MAXIMUM DETECTION RANGE
C          RL = MAXIMUM LETHAL RANGE OF ASSOCIATED WEAPON
C          PMAX = MAXIMUM PRIORITY OUTSIDE LETHAL RANGE
C          PPMAX = MAXIMUM INCREASE IN PRIORITY WITHIN LETHAL RANGE
C          FM = PRIORITY ROLL-OFF EXPONENT FOR RANGES WITHIN RL
C          FN = PRIORITY ROLL-OFF EXPONENT FOR RANGES OUTSIDE RL
C          FREQ = RADAR FREQUENCY
C          RPWR = RADAR PEAK POWER OUTPUT
C          GMAX = MAXIMUM RADAR ANTENNA GAIN
C          BEAM = ANTENNA HALF POWER BEAMWIDTH
C          AVGSLL = AVERAGE SIDE LOBE LEVEL
C          ITRAK = 0 FOR ACQUISITION RADARS
C                  1 FOR TRACKING RADARS
C          FMOD = RADAR VULNERABILITY TO JAMMER MODULATION
C
      READ(1,0190)(RADN1(I),RADN2(I),RMAX(I),RL(I),PMAX(I),PPMAX(I),FM(I
     1),FN(I),FREQ(I),RPWR(I),GMAX(I),BEAM(I),AVGSLL(I),ITRAK(I),FMOD(I)
     2,I=1,NTAB)
0190  FORMAT(2A4,6F10.4,/,2E12.4,3F10.6,I1,F10.6)
```

```
C
C
C
C     DETERMINE THE SCALE FACTOR(SKAL) FOR THE LONGITUDE DISTANCES
C
      SKAL=COS(ALAT/57.29577951)
C
C     SHIFT THE OPERATING AREA TO A 0/0 REFERENCE POINT AND DIMENSION IN
C     MINUTES OF LATITUDE AND LONGITUDE
      DO 0210 I=1,NTOT
      RLAT(I)=DGMN(RLAT(I))-DGMN(ALAT)
      RLON(I)=(DGMN(RLON(I))-DGMN(ALON))*SKAL
0210  CONTINUE
      DO 0215 I=1,ISTK
      SLAT(I)=DGMN(SLAT(I))-DGMN(ALAT)
      SLON(I)=(DGMN(SLON(I))-DGMN(ALON))*SKAL
0215  CONTINUE
C
C
C     DETERMINE THE INTEGER DIMENSIONS OF THE OPERATING AREA
      LAT=DGMN(BLAT)-DGMN(ALAT)+.1
      LON=DGMN(BLON)-DGMN(ALON)+.1
C
C     DETERMINE THE ALLOWABLE POSITIONS FOR THE ECM AIRCRAFT(IMITE=1)
      DO 0220 I=1,LAT
      DO 0220 J=1,LON
      IMITE(I,J)=0
      PLAT=I
      PLON=J*SKAL
      CALL KURAJ(PLAT,PLON,RLAT,RLON,ELNT1,ELNT2,NTOT,DXPOZ,NTAB,RADN1,
     1RADN2,RL,FM)
C     DXPOZ IS THE DEGREE  OF EXPOSURE AT POINT I,J
      IF(DXPOZ.GT.PUKR)IMITE(I,J)=-1
0220  CONTINUE
      IMITE(LAB,LOB)=1
C
C     REMOVE THE ALLOWABLE POINTS THAT ARE INACCESIBLE
C     FIRST, SHIFT THE ARRAY IMITE ONE UNIT UP IN LAT AND LON
      LAT1=0
      LON1=0
      LA1=LAT+1
      LO1=LON+1
      LA2=LAT+2
      LO2=LON+2
      DO 0230 M=1,LAT
      DO 0230 N=1,LON
      K=LA2-M
      L=LO2-N
```

```
      I=LA1-M
      J=LC1-N
      IMITE(K,L)=IMITE(I,J)
0230  CONTINUE
C     NEW FRAME IMITE IN -1'S (ALLOWS NO FLIGHTS OUT OF AREA)
      DO 0240 IN=1,LA2
      IMITE(IN,1)=-1
      IMITE(IN,LO2)=-1
0240  CONTINUE
      DO 0250 IN=1,LO2
      IMITE(1,IN)=-1
      IMITE(LA2,IN)=-1
0250  CONTINUE
C
C     NOW SWEEP REPEATEDLY ACROSS IMITE SETTING ACCESSIBLE 0'S TO 1
      NUD=2*LAT
      DO 0260 NSWEP=1,NUD
      DO 0260 M=2,LA1
      DO 0260 N=2,LO1
C     LOCATE THE START POINT OR EVENTUAL ACCESSIBLE POINTS
      IF(IMITE(M,N).NE.1)GO TO 0260
C     CHANGE EVERY ACCESSIBLE ZERO FROM THIS POINT TO 1
      IF(IMITE(M,N-1).EQ.0)IMITE(M,N-1)=1
      IF(IMITE(M+1,N-1).EQ.0)IMITE(M+1,N-1)=1
      IF(IMITE(M+1,N).EQ.0)IMITE(M+1,N)=1
      IF(IMITE(M+1,N+1).EQ.0) IMITE(M+1,N+1)=1
      IF(IMITE(M,N+1).EQ.0)IMITE(M,N+1)=1
      IF(IMITE(M-1,N+1).EQ.0)IMITE(M-1,N+1)=1
      IF(IMITE(M-1,N).EQ.0)IMITE(M-1,N)=1
      IF(IMITE(M-1,N-1).EQ.0)IMITE(M-1,N-1)=1
0260  CONTINUE
C     REMOVE THE FRAME AND SHIFT IMITE ONE UNIT DOWN IN LAT/LON
      DO 0270 M=1,LAT
      DO 0270 N=1,LON
      IMITE(M,N)=IMITE(M+1,N+1)
0270  CONTINUE
C
C     DETERMINE THE STRIKE ROUTE POINT OF HIGHEST TOTAL PRIORITY. THIS
C     POINT WILL BE A MUST POINT LATER FOR HIGHEST JAMMING EFFECTIVENESS
C     ITERATE FOR EACH STRIKE GROUP POINT
      PTEMP=0.
      DO 0350 I=1,ISTK
      TPRTY(I)=0.
C     ITERATE FOR EACH RADAR IN THE EOB
      DO 0340 J=1,NTOT
C     SEARCH THE PARAMETER TABLE FOR THIS RADAR
      DO 0330 K=1,NTAB
      IF((RADN1(K).EQ.ELNT1(J)).AND.(RADN2(K).EQ.ELNT2(J)))GO TO 0331
```

```
0330  CONTINUE
0331  CONTINUE
C     DETERMONE THE RANGE FROM THIS RADAR TO THE STRIKE
      R=RANJ(SLAT(I),SLON(I),RLAT(J),RLON(J))
C     BASED ON THIS RANGE ASSIGN THE PROPER PRIORITY TO THE RADAR
      IF(R.LE.RL(K))PRTY(I,J)=PPMAX(K)*(1.-(R/RL(K))**FM(K))+PMAX(K)
      IF((R.GT.RL(K)).AND.(R.LE.RMAX(K)))PRTY(I,J)=PMAX(K)*(1.-(R/RMAX(K
     1))**FN(K))
      IF(R.GT.RMAX(K))PRTY(I,J)=0.
C     DETERMINE THE TOTAL PRIORITY(TPRTY) AT THIS STRIKE POSITION
      TPRTY(I)=TPRTY(I)+PRTY(I,J)
0340  CONTINUE
C     OUTPUT THE TOTAL PRIORITY FOR EACH STRIKE GROUP POSITION TO
C     OBSERVE HOW IT FALLS OFF FROM MAXIMUM EXPOSURE POINT.
C     THIS ROLL-OFF WILL INDICATE HOW CLOSE THE ROUTE TO BE
C     GENERATED WILL COME TO AN ABSOLUTE OPTIMUM ROUTE.
      WRITE(6,0341)TPRTY(I)
0341  FORMAT(20X,E16.8)
C     RETAIN THE HIGHEST PRIORITY STRIKE POINT(IMAX)
      IF(TPRTY(I).LE.PTEMP)GO TO 0350
      PTEMP=TPRTY(I)
      IMAX=I
0350  CONTINUE
C
C
C     DIVIDE THE STRIKE ROUTE INTO TWO SECTIONS ABOUT THE HIGHEST
C     PRIORITY POINT(IMAX)
      ISTK1=IMAX
      ISTK2=ISTK-IMAX+1
      DO 0400 I=1,ISTK1
      J=IMAX+1-I
      SLAT1(I)=SLAT(J)
      SLON1(I)=SLON(J)
      DO 0400 KK=1,NTOT
      PRTY1(I,KK)=PRTY(J,KK)
0400  CONTINUE
      DO 0410 I=1,ISTK2
      J=IMAX-1+I
      SLAT2(I)=SLAT(J)
      SLON2(I)=SLON(J)
      DO 0410 KK=1,NTOT
      PRTY2(I,KK)=PRTY(J,KK)
0410  CONTINUE
C
C     DETERMINE THE ANTENNA PATTERNS FOR THE RADARS
      DO 0440 I=1,NTOT
C     SEARCH THE PARAMETER TABLE FOR THIS RADAR
      DO 0430 J=1,NTAB
```

```
      IF((RADN1(J).EQ.ELNT1(I)).AND.(RADN2(J).EQ.ELNT2(I)))GO TO 0431   MAN02410
0430  CONTINUE                                                          MAN02420
0431  CONTINUE                                                          MAN02430
      CALL ANTDB(GMAX(J),BEAM(J),AVGSLL(J),FREQ(J),ITRAK(J),GN)         MAN02440
      DO 0435 KL=1,180                                                  MAN02450
      G(I,KL)=GN(KL)                                                    MAN02460
0435  CONTINUE                                                          MAN02470
0440  CONTINUE                                                          MAN02480
      DO 0461 KL=1,10                                                   MAN02490
      LT1(KL)=0                                                         MAN02500
      LN1(KL)=0                                                         MAN02510
      TCTP(KL)=0.                                                       MAN02520
0461  CONTINUE                                                          MAN02530
C     CHANGE ALL MAXIMUM ANTENNA GAIN VALUES FROM DB TO LINEAR          MAN02540
      DO 0462 I=1,NTAB                                                  MAN02550
      GMAX(I)=10.**(GMAX(I)/10.)                                        MAN02560
0462  CONTINUE                                                          MAN02570
C                                                                       MAN02580
C     DETERMINE THE ORDER OF PRIORITY                                   MAN02590
      CALL ORDER(PRTY,NTOT,NPRTY,IMAX)                                  MAN02600
C                                                                       MAN02610
C                                                                       MAN02620
C     DETERMINE THE TEN  BEST LOCATIONS FOR THE JAMMER AT THE STRIKE    MAN02630
C     GROUP'S HIGHEST PRIORITY POINT                                    MAN02640
C     ITERATE FOR ALLOWABLE OPERATING POINTS                            MAN02650
      DO 0490 M=1,LAT                                                   MAN02660
      DO 0490 N=1,LON                                                   MAN02670
      IF(IMITE(M,N).NE.1)GO TO 0490                                     MAN02680
C     ADJUST THIS POINT TO THE OPERATING AREA DISTANCE SCALE            MAN02690
      PLAT=M                                                            MAN02700
      PLON=N*SKAL                                                       MAN02710
                                                                        MAN02720
C     INITIALIZE THE TOTAL EFFECTIVENESS VALUE(TEFF) TO ZERO            MAN02730
      TEFF=0.                                                           MAN02740
C     ITERATE FOR RADARS IN DESCENDING ORDER OF PRIORITY                MAN02750
      DO 0485 I=1,NTOT                                                  MAN02760
      DO 0465 J=1,NTAB                                                  MAN02770
      IF((RADN1(J).EQ.ELNT1(NPRTY(I))).AND.(RADN2(J).EQ.ELNT2(NPRTY(I)))MAN02780
     1)GO TO 0466                                                       MAN02790
0465  CONTINUE                                                          MAN02800
0466  CONTINUE                                                          MAN02810
C     CHECK TO SEE IF A JAMMER IS AVAILABLE                             MAN02820
      DO 0470 K=1,NJAM                                                  MAN02830
      IF((FREQ(J).LT.F1(K)).OR.(FREQ(J).GT.F2(K))) GO TO 0470           MAN02840
      IF(JXN(K).EQ.0)GO TO 0470                                         MAN02850
      JXN(K)=0                                                          MAN02860
C     JAMMER K IS AVAILABLE                                             MAN02870
      GO TO 0472                                                        MAN02880
```

```
0470  CONTINUE
C     NO JAMMER IS AVAILABLE GO TO NEXT RADAR
      GO TO 0485
0472  CONTINUE
C     COMPUTE THE J/S
C     FIRST COMPUTE THE RADAR- STRIKE(RSTK) AND RADAR-JAMMER(RJX) RANGES
      RSTK=1852.*RANJ(RLAT(NPRTY(I)),RLON(NPRTY(I)),SLAT(IMAX),SLON(IMAX
     1))
      RJX=1852.*RANJ(RLAT(NPRTY(I)),RLON(NPRTY(I)),PLAT,PLON)
C     SET THE MINIMUM RANGE TO ONE NAUTICAL MILE. THIS WILL PREVENT
C     THE J/S FROM GOING TO INFINITY FOR JAMMER POSITIONS OVERHEAD
C     A RADAR SITE
      IF(RSTK.LT.1852.)RSTK=1852.
      IF(RJX.LT.1852.)RJX=1852.
C     MEASURE THE STRIKE-RADAR-JAMMER ANGLE (THETA)
      THETA=ABS((ATAN2(RLON(NPRTY(I))-SLON(IMAX),RLAT(NPRTY(I))-SLAT(IMA
     1X)))-(ATAN2(RLON(NPRTY(I))-PLON,RLAT(NPRTY(I))-PLAT)))*57.2957795
      IF(THETA.GT.180.)THETA=360.-THETA
      ITHETA=THETA+1.
C     COMPUTE THE J/S (EFCT)
      EFCT=((49*3.141592654*PWR(K)*(10.**(GAN(K)/10.))*G(NPRTY(I),ITHETA
     1)*RSTK**4)/(RPWR(J)*GMAX(J)**2*CRSCT*RJX**2))
C     CONVERT THE J/S TO DB AND LIMIT IT TO A RANGE OF -25DB TO +50DB
C     NORMALIZE THIS RANGE ZERO TO ONE
      EFCT=((20.*ALOG10(EFCT))/50.+.5)/1.5
      IF(EFCT.GT.1.)EFCT=1.
      IF(EFCT.LT.0.)EFCT=0.
C     WEIGHT THE J/S BY THE PRIORITY AND THE MODULATION VULNERABILITY
C     (FMOD) OF THE ASSOCIATED RADAR
      PERF=EFCT*PRTY(IMAX,NPRTY(I))*FMOD(J)
C     SUM THE PERFORMANCES AGAINST THE INDIVIDUAL RADARS FOR A TOTAL
C     PERFORMANCE (TEFF) INDICATION FROM THIS JAMMER LOCATION
      TEFF=TEFF+PERF
0485  CONTINUE
C     RETAIN THE TEN BEST PERFORMANCE POINTS
      CALL GDPTS(M,N,TEFF,LT1,LN1,TOTP)
C
C     RESET THE JAMMER AVAILABILITY
      DO 0490 JI=1,NJAM
      JXN(JI)=1
0490  CONTINUE
C    OUTPUT THE TEN BEST LOCATIONS FOR THE JAMMER FOR THE STRIKE GROUP'S
C    HIGHEST EXPOSURE POINT
      WRITE(6,0471)(LT1(I),LN1(I),TOTP(I),I=1,10)
0471  FORMAT(2I5,E16.8)
C
C     SET THE INITIAL ECM ROUTE POINTS TO THE BEST POINTS AT IMAX
      DO 0600 I=1,10
```

```
      ELAT1(1,I)=LT1(I)
      ELAT2(1,I)=LT1(I)
      ELON1(1,I)=LN1(I)
      ELON2(1,I)=LN1(I)
0600  CONTINUE
C
C     ITERATE FOR THE TEN IMAX POINTS
      DO 0800 I=1,10
      R1FACT(I)=0.
      R2FACT(I)=0.
C      ITERATE FOR ROUTE SEGMENT ONE
      IS1=ISTK1-1
      IF(IS1.EQ.0)GO TO 0650
      DO 0650 J=1,IS1
      CALL ORDER(PRTY1,NTOT,NPRTY,J)
C     ITERATE FOR THE POINTS IN THE OPERATING AREA
      TLAST=0.
      DO 0640 M=1,LAT
      DO 0640 N=1,LON
C     THROW OUT POINTS THAT ARE NOT ALLOWED OR TOO FAR FROM PREVIOUS PT
      PLAT=M
      PLON=N*SKAL
      IF((IMITE(M,N).NE.1).OR.(RANJ(PLAT,PLON,ELAT1(J,I),ELON1(J,I)*SKAL
     1).GT.DMAX))GO TO 0640
      TEFF=0.
C     ITERATE FOR RADARS IN THE EOB IN DESCENDING ORDER OF PRIORITY
      DO 0630 K=1,NTOT
C     SEARCH THE PARAMETER TABLE
      DO 0605 II=1,NTAB
      IF((RADN1(II).EQ.ELNT1(NPRTY(K))).AND.(RADN2(II).EQ.ELNT2(NPRTY(K)
     1))) GO TO 0606
0605  CONTINUE
0606  CONTINUE
C     CHECK TO SEE IF A JAMMER IS AVAILABLE
      DO 0620 L=1,NJAM
      IF((FREQ(II).LT.F1(L)).OR.(FREQ(II).GT.F2(L)))GO TO 0620
      IF(JXN(L).EQ.0)GO TO 0620
      JXN(L)=0.
C     JAMMER L IS AVAILABLE
      GO TO 0621
0620  CONTINUE
C     NO JAMMER IS AVAILABLE, GO TO NEXT LOWER PRIORITY RADAR
      GO TO 0630
0621  CONTINUE
C     COMPUTE THE J/S
C     FIRST MEASURE THE DISTANCE FROM THE RADAR TO THE STRIKE AND JAMMER
      RSTK=1852.*RANJ(RLAT(NPRTY(K)),RLON(NPRTY(K)),SLAT1(J+1),SLON1(J
     1+1))
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```
      RJX=1852.*RANJ(RLAT(NPRTY(K)),RLON(NPRTY(K)),PLAT,PLON)           MAN03850
C     LIMIT THE RANGES TO ONE NAUTICAL MILE. THIS KEEPS THE J/S FROM    MAN03860
C     GOING TO INFINITY FOR JAMMER LOCATIONS OVERHEAD A RADAR.          MAN03870
      IF(RSTK.LT.1852.)RSTK=1852.                                       MAN03880
      IF(RJX.LT.1852.)RJX=1852.                                         MAN03890
C     MEASURE THE STRIKE-RADAR-JAMMER ANGLE                             MAN03900
      THETA=ABS((ATAN2(RLON(NPRTY(K))-SLON1(J+1),RLAT(NPRTY(K))-SLAT1(J+MAN03910
     1))))-(ATAN2(RLON(NPRTY(K))-PLON,RLAT(NPRTY(K))-PLAT)))*57.29577951MAN03920
      IF(THETA.GT.180.)THETA=360.-THETA                                 MAN03930
C     COMPUTE THE J/S (EFCT)                                            MAN03940
      EFCT=((4.*3.141592654*PWR(L)*(10.**(GAN(L)/10.))*G(NPRTY(K),THETA+MAN03950
     11)*RSTK**4)/(RPWR(II)*GMAX(II)**2*CRSCT*RJX**2))                  MAN03960
C     CONVERT THE J/S TO DB AND LIMIT IT TO A RANGE OF -25DB TO +50DB   MAN03970
C     NORMALIZE THIS RANGE ZERO TO ONE                                  MAN03980
      EFCT=((20.*ALOG10(EFCT))/50.+.5)/1.5                              MAN03990
      IF(EFCT.GT.1.)EFCT=1.                                             MAN04000
      IF(EFCT.LT.0.)EFCT=0.                                             MAN04010
C     WEIGHT THE J/S BY THE PRIORITY AND MODULATION VULNERABILITY       MAN04020
      PERF=EFCT*PRTY1(J+1,NPRTY(K))*FMOD(II)                            MAN04030
C     SUM THE PERFORMANCES AGAINST THE INDIVIDUAL RADARS FOR A TOTAL    MAN04040
C     PERFORMANCE INDICATOR FROM THIS JAMMER LOCATION                   MAN04050
      TEFF=TEFF+PERF                                                    MAN04060
0630  CONTINUE                                                          MAN04070
C     RETAIN THE BEST POINT AS AN ECM ROUTE POINT                       MAN04080
      IF(TEFF.LT.TLAST)GO TO 0635                                       MAN04090
      TLAST=TEFF                                                        MAN04100
      ELAT1(J+1,I)=M                                                    MAN04110
      ELON1(J+1,I)=N                                                    MAN04120
C     RESET THE JAMMER AVAILABILITY                                     MAN04130
0635  DO 0640 JN=1,NJAM                                                 MAN04140
      JXN(JN)=1                                                         MAN04150
0640  CONTINUE                                                          MAN04160
      R1FACT(I)=R1FACT(I)+TLAST                                         MAN04170
0650  CONTINUE                                                          MAN04180
C     ITERATE FOR ROUTE SEGMENT TWO                                     MAN04190
      IS2=ISTK2-1                                                       MAN04200
      IF(IS2.EQ.0)GO TO 0750                                            MAN04210
      DO 0750 J=1,IS2                                                   MAN04220
      CALL ORDER(PRTY2,NTOT,NPRTY,J)                                    MAN04230
C     ITERATE FOR POINTS IN THE OPERATING AREA                          MAN04240
      TLAST=0.                                                          MAN04250
      DO 0740 M=1,LAT                                                   MAN04260
      DO 0740 N=1,LON                                                   MAN04270
C     THROW OUT THE POINTS THAT ARE NOT ALLOWED OR TOO FAR FROM PREVIOUSMAN04280
      PLAT=M                                                            MAN04290
      PLON=N*SKAL                                                       MAN04300
      IF((IMITE(M,N).NE.1).OR.(RANJ(PLAT,PLON,ELAT2(J,I),ELON2(J,I)*SKALMAN04310
     1).GT.DMAX))GO TO 0740                                             MAN04320
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```
      TEFF=0.
C     ITERATE FOR THE RADARS IN THE OPERATING AREA
      DO 0730 K=1,NTOT
C     SEARCH THE PARAMETER TABLE
      DO 0705 II=1,NTAB
      IF((RADN1(II).EQ.ELNT1(NPRTY(K))).AND.(RADN2(II).EQ.ELNT2(NPRTY(K)
     1))) GO TO 0706
0705  CONTINUE
0706  CONTINUE
C     CHECK TO SEE IF A JAMMER IS AVAILABLE
      DO 0720 L=1,NJAM
      IF((FREQ(II).LT.F1(L)).OR.(FREQ(II).GT.F2(L)))GO TO 0720
      IF(JXN(L).EQ.0)GO TO 0720
      JXN(L)=0
C     JAMMER L IS AVAILABLE
      GO TO 0721
0720  CONTINUE
C     NO JAMMER AVAILABLE
      GO TO 0730
0721  CONTINUE
C     COMPUTE THE J/S
C     FIRST MEASURE THE RANGE FROM THE RADAR TTC THE STRIKE
C     AND JAMMER
      RSTK=1852.*RANJ(RLAT(NPRTY(K)),RLON(NPRTY(K)),SLAT2(J+1),SLON2(J+1
     1))
      RJX=1852.*RANJ(RLAT(NPRTY(K)),RLON(NPRTY(K)),PLAT,PLON)
C     LIMIT THE MINIMUM RANGE TO ONE NAUTICAL MILE. THIS WILL KEEP
C     THE J/S FROM GOING TO INFINITY FOR JAMMER LOCATIONS OVERHEAD A
C     RADAR SITE
      IF(RSTK.LT.1852.)RSTK=1852.
      IF(RJX.LT.1852.)RJX=1852.
C     MEASURE THE STRIKE-RADAR-JAMMER ANGLE
      THETA=ABS((ATAN2(RLON(NPRTY(K))-SLON2(J+1),RLAT(NPRTY(K))-SLAT2(J+
     11)))-(ATAN2(RLON(NPRTY(K))-PLON,RLAT(NPRTY(K))-PLAT)))*57.29577951
      IF(THETA.GT.180.)THETA=360.-THETA
C     COMPUTE THE J/S
      EFCT=((4.*3.141592654*PWR(L)*(10.**(GAN(L)/10.))*G(NPRTY(K),THETA+
     11)*RSTK**4)/(RPWR(II)*GMAX(II)**2*CRSCT*RJX**2))
C     CONVERT THE J/S TO DB AND LIMIT IT TO A RANGE OF -25DB TO +50DB
C     NORMALIZE THIS RANGE ZERO TO ONE
      EFCT=((20.*ALOG10(EFCT))/50.+.5)/1.5
      IF(EFCT.GT.1.)EFCT=1.
      IF(EFCT.LT.0.)EFCT=0.
C     WEIGHT THE J/S BY THE PRIORITY AND MODULATION VULNERABILITY
      PERF=EFCT*PRTY2(J+1,NPRTY(K))*FMOD(II)
C     SUM THE INDIVIDUAL PERFORMANCES FOR A TOTAL PERFORMANCE INDICATOR
C     FROM THIS JAMMER LOCATION
      TEFF=TEFF+PERF
```

```
073C   CONTINUE
C      RETAIN THE BEST POINT AS AN ECM ROUTE POINT
       IF(TEFF.LT.TLAST)GO TO 0735
       TLAST=TEFF
       ELAT2(J+1,I)=M
       ELON2(J+1,I)=N
C      RESET THE JAMMER AVAILABILITY
0735   DO 0740 JN=1,NJAM
       JXN(JN)=1
074C   CONTINUE
       R2FACT(I)=R2FACT(I)+TLAST
075C   CONTINUE
       TOTP(I)=TOTP(I)+R1FACT(I)+R2FACT(I)
080C   CONTINUE
C      SHIFT THE 0/0 REFERENCED AREA USED DURING CALCULATIONS BACK
C      TO ITS INITIAL LAT/LON. OUTPUT THE ROUTE NUMBER, MEASURE OF
C      EFFECTIVENESS, AND ROUTE POINTS.
       DO 0900 I=1,10
       WRITE(6,0805)I,TOTP(I)
0805   FORMAT(/,2X,I3,5X,E16.8)
       DO 0850 J=1,ISTK1
       AA=(DGMN(ALAT)+ELAT1(J,I)+.1)/60.
       BB=(DGMN(ALON)+ELON1(J,I)+.1)/60.
       ELAT1(J,I)=(AA-INT(AA))*.6+INT(AA)
       ELON1(J,I)=(BB-INT(BB))*.6+INT(BB)
085C   CONTINUE
       DO 0870 J=1,ISTK2
       CC=(DGMN(ALAT)+ELAT2(J,I)+.1)/60.
       DD=(DGMN(ALON)+ELON2(J,I)+.1)/60.
       ELAT2(J,I)=(CC-INT(CC))*.6+INT(CC)
       ELON2(J,I)=(DD-INT(DD))*.6+INT(DD)
0870   CONTINUE
       DO 0890 KK=1,ISTK1
       K=ISTK1-KK+1
       WRITE(6,0875)ELAT1(K,I),ELON1(K,I)
0875   FORMAT(10X,F10.2,5X,F10.2)
089C   CONTINUE
       IF(ISTK2.EQ.1)GO TO 0895
       WRITE(6,0875)(ELAT2(LL,I),ELON2(LL,I),LL=2,ISTK2)
0895   CONTINUE
090C   CONTINUE
       STOP
       END
       FUNCTION RANJ(Y1,X1,Y2,X2)
C      RANJ DETERMINES THE RANGE BETWEEN (X1,Y1) AND (X2,Y2)
       RANJ=SQRT((Y1-Y2)**2+(X1-X2)**2)
       RETURN
       END
```

```
      FUNCTION DGMN(X)
C     DGMN CONVERTS DEGREES AND MINUTES FROM DD.MM FORMAT TO
C     MINUTES ONLY
      DGMN=(X-INT(X))*100.+INT(X)*60.
      RETURN
      END
      SUBROUTINE KURAJ(PLAT,PLON,RLAT,RLON,ELNT1,ELNT2,NTOT,DXPOZ,NEOB,
     1RADN1,RADN2,RL,FM)
C     KURAJ DETERMINES THE EXPOSURE OF A POINT IN THE OPERATING AREA
C     AND RETURNS IT AS DXPOZ.
      DIMENSION RLAT(50),RLON(50),ELNT1(50),ELNT2(50),RADN1(50),RADN2(50
     1),RL(50),FM(50)
      INTEGER RADN1,RADN2,ELNT1,ELNT2
      DXPOZ=0.
      PUKRF=1.
C     ITERATE FOR EACH RADAR IN THE EOB
      DO 200 I=1,NTOT
C     SEARCH THE PARAMETER TABLE FOR THIS RADAR
      DO 210 J=1,NEOB
      IF((RADN1(J).EQ.ELNT1(I)).AND.(RADN2(J).EQ.ELNT2(I)))GO TO 211
210   CONTINUE
211   CONTINUE
C     CHECK TO SEE IF THE RADAR IS A THREAT RADAR (RL > 0)
      IF(RL(J).EQ.0.)GO TO 200
C     MEASURE THE RANGE FROM THE STRIKE TO THE RADAR
      R=RANJ(PLAT,PLON,RLAT(I),RLON(I))
C     IF THE STRIKE IS WITHIN THE LETHAL RANGE COMPUTE THE EXPOSURE
      IF(R.LT.RL(J))PUKRF=PUKRF*(R/RL(J))**FM(J)
      DXPOZ=1.-PUKRF
200   CONTINUE
      RETURN
      END
      SUBROUTINE ANTDB(GAIN,BEAM,AVGSLL,FREQ,ITRAK,RFACT)
C     ANTDB GENERATES 180 DEGREES OF AN ANTENNA PATTERN. IT IS
C     ASSUMED THAT THE PATTERN IS SYMMETRIC FOR THE OTHER 180 DEGREES.
C     THE APERTURE E-FIELD DISTRIBUTION IS ASSUMED UNIFORM FOR
C     TRACKING RADARS AND FIRST ORDER COSINE FOR EW/ACQ RADARS.
      DIMENSION BNUL(180),PATRN(180),RFACT(181)
      PI=3.141592654
C     DETERMINE THE WAVELENGTH (WAVE) AT THE FREQUENCY (FREQ)
      WAVE=299792500./FREQ
C     DETERMINE THE APERTURE DIMENSION FOR AN ACQ RADAR
      APERT=(69.*WAVE)/BEAM
C     CONVERT GAIN FROM DB TO LINEAR
      GAIN=10.**(GAIN/10.)
C     CONVERT AVERAGE SIDE LOBE LEVEL FROM DB TO LINEAR
      AVGSLL=(10.**(AVGSLL/10.))/GAIN
C     IF THE RADAR IS A TRACKER RECOMPUTE THE APERTURE
```

```
      IF(ITRAK.EQ.1)APERT=(51.*WAVE)/BEAM                               SBR00540
      PATRN(1)=1.                                                       SBR00550
C     ITERATE FOR 180 DEGREES IN ONE DEGREE INCREMENTS                  SBR00560
      DO 200 N=1,180                                                    SBR00570
C     SET THE VALUE OF PSI DEPENDING ON WHETHER THE RADAR IS A          SBR00580
C     TRACKER OR ACQ TO THE VALUE WHERE THE PATTERN NULLS OCCUR         SBR00590
      PSI=(N+.5)*PI                                                     SBR00600
      IF(ITRAK.EQ.1)PSI=N*PI                                            SBR00610
C     COMPUTE THE POSITION OF THE PATTERN NULLS                         SBR00620
      BNUL(N)=ARSIN((PSI*WAVE)/(PI*APERT))*57.29577951                  SBR00630
C     SET PSI TO THE VALUE WHERE THE PATTERN MAXIMA OCCUR               SBR00640
      PSI=(N+1)*PI                                                      SBR00650
      IF(ITRAK.EQ.1)PSI=(N+.5)*PI                                       SBR00660
C     COMPUTE THE VALUES OF THE PATERN MAXIMA                           SBR00670
      PATRN(N+1)=(ABS((PI/4.)*(((SIN(PSI+PI/2.))/(PSI+PI/2.))+((SIN(P   SBR00680
     1SI-PI/2.))/(PSI-PI/2.)))))**2)                                    SBR00690
      IF(ITRAK.EQ.1)PATRN(N+1)=(ABS((SIN(PSI))/PSI))**2                 SBR00700
C     CHECK TO SEE IF THE PATTERN MAXIMA HAVE FALLEN BELOW THE          SBR00710
C     AVERAGE SIDE LOBE LEVEL                                           SBR00720
      IF(PATRN(N+1).LT.AVGSLL)GO TO 300                                 SBR00730
C     IF THE LOBE POSITIONS ARE GETTING CLOSE TO 90 DEG. GO AHEAD AND   SBR00740
C     SET THE PATTERN TO THE SIDE LOBE LEVEL SINCE TAKING THE ARCSIN    SBR00750
C     OF VALUES GREATER THAN ONE WILL CAUSE AN ERROR                    SBR00760
      IF(BNUL(N).GT.80.)GO TO 300                                       SBR00770
  200 CONTINUE                                                          SBR00780
  300 CONTINUE                                                          SBR00790
      BNUL(N+1)=181                                                     SBR00800
C     SET THE VALUE OF THE PATTERN TO THE VALUE OF THE PARTICULAR       SBR00810
C     SET THE INTERMEDIATE PATTERN VALUES TO THE MAXIMUM VALUE OF       SBR00820
C     THE SIDE LOBE WHICH THEY LIE IN TO ELIMINATE THE NARROW NULLS     SBR00830
      RFACT(181)=AVGSLL*GAIN                                            SBR00840
      L=0                                                               SBR00850
      DO 500 K=1,180                                                    SBR00860
      M=L+1                                                             SBR00870
      IF(K.GT.BNUL(L+1))L=L+1                                           SBR00880
      RFACT(K)=PATRN(M)*GAIN                                            SBR00890
  500 CONTINUE                                                          SBR00900
C     RESET THE GAIN TO DB                                              SBR00910
      GAIN=10.*(ALOG10(GAIN))                                           SBR00920
      RETURN                                                            SBR00930
      END                                                               SBR00940
      SUBROUTINE GDPTS(M,N,TEFF,LT,LN,TOTP)                             SBR00950
C     GDPTS SORTS THE PERFORMANCES AND RETAINS THE TEN BEST             SBR00960
C     PERFORMANCES AND THEIR POSITIONS.                                 SBR00970
      DIMENSION LT(10),LN(10),TOTP(10)                                  SBR00980
      DO 500 K=1,10                                                     SBR00990
      IF(TEFF.LE.TOTP(K))GO TO 500                                      SBR01000
      KK=10-K                                                           SBR01010
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      DO 400 J=1,KK                                                     SBR01020
      LL=11-J                                                           SBR01030
      MM=10-J                                                           SBR01040
      LT(LL)=LT(MM)                                                     SBR01050
      LN(LL)=LN(MM)                                                     SBR01060
      TCTP(LL)=TCTP(MM)                                                 SBR01070
400   CONTINUE                                                          SBR01080
      LT(K)=M                                                           SBR01090
      LN(K)=N                                                           SBR01100
      TCTP(K)=TEFF                                                      SBR01110
      GO TO 600                                                         SBR01120
500   CONTINUE                                                          SBR01130
600   CONTINUE                                                          SBR01140
      RETURN                                                            SBR01150
      END                                                               SBR01160
      SUBROUTINE ORDER(PRTY,NTOT,NPRTY,ISTK)                            SBR01170
C     ORDER ARRANGES THE PRIORITIES IN DESCENDING ORDER BY              SBR01180
C     SUBSCRIPTS ONLY. ONLY THE SUBSCRIPTS ARE COMPUTED; THE PRIORITY   SBR01190
C     ARRAY IS NOT REARRANGED.                                          SBR01200
      DIMENSION PRTY(50,50),PRTEMP(50),NPRTY(50)                        SBR01210
      DO 1100 I=1,NTOT                                                  SBR01220
      PRTEMP(I)=0.                                                      SBR01230
1100  CONTINUE                                                          SBR01240
      DO 1160 I=1,NTOT                                                  SBR01250
      DO 1150 K=1,NTOT                                                  SBR01260
      IF(PRTY(ISTK,I).LE.PRTEMP(K))GO TO 1150                           SBR01270
      KK=NTOT-K                                                         SBR01280
      IF(KK.EQ.0)GO TO 1140                                             SBR01290
      DO 1140 J=1,KK                                                    SBR01300
      LL=NTOT+1-J                                                       SBR01310
      MM=NTOT-J                                                         SBR01320
      PRTEMP(LL)=PRTEMP(MM)                                             SBR01330
      NPRTY(LL)=NPRTY(MM)                                               SBR01340
1140  CONTINUE                                                          SBR01350
      PRTEMP(K)=PRTY(ISTK,I)                                            SBR01360
      NPRTY(K)=I                                                        SBR01370
      GO TO 1160                                                        SBR01380
1150  CONTINUE                                                          SBR01390
1160  CONTINUE                                                          SBR01400
      RETURN                                                            SBR01410
      END                                                               SBR01420
C     SAMPLE EMITTER PARAMETER TABLE FOR AN ACQ, SAM, AND AAA RADAR.
C ELINT NO., MAX DETECTION RANGE, MAX LETHAL RANGE, PMAX, P'MAX, M, N
C FREQ, POWER, MAX RANGE, MAX LETHAL RANGE, SIDE LOBE LEVEL, ITRAK, FMOD, , , ,
A100Z   100.       0.        0.3        0.         0.         4.
     1.5E 09      1.0E 0640.0      1.5        -2.        0 1.0
A200Z   60.        30.       0.3        0.6        7.         4.
     2.5E 09      0.6E 0640.       1.0        5.0        1 1.0
```

```
A300Z  40.      8.     0.3     C.65    7.      4.
    3.5E 09   0.4E 0640.   1.0     5.0      1 1.0
```

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